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APPLICATION OF STOCHASTIC APPROXIMATION THEORY TO FIELD ARTILLERY PRECISION FIRE

Milivoy Tratensek

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THESIS

APPLICATION OF STOCHASTIC APPROXIMATION THEORY TO FIELD ARTILLERY PRECISION FIRE

by

Milivoj Tratensek

Thesis Advisor: D. R. Barr

June 1973

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Application of Stochastic Approximation Theory
to
Field Artillery Precision Fire

by

Milivoj Tratensek
Captain, United States Army
B.S., United States Military Academy, 1964

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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June 1973

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ABSTRACT

This thesis is addressed to the problem of determining optimal precision fire methods for the Field Artillery. The current precision fire technique has been in use by the Field Artillery since 1941. Because of the general acceptance that the method works, the procedure has remained relatively unchanged for 32 years; no documented evidence of previous efforts to establish an analytical basis for the procedure apparently exists. Employing the methods of stochastic approximation, the theoretical foundation for the current procedure is established. Using the developed theoretical foundation of the current precision fire method, a simplified, more efficient procedure is developed. In addition, an optimal precision fire procedure to be used when forward observers are equipped with laser range finders is presented. The procedures are compared analytically and through computer simulations to arrive at conclusions regarding simplicity, accuracy and economy of ammunition expenditures.

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EXECUTIVE SUMMARY

The current field artillery precision fire technique for registration and destruction, as described in Field Manual FM 6-40, has been in use since 1941. Procedurally, it has remained relatively unchanged for 32 years because of the acceptance that it "works". It appears that no documented efforts have heretofore been made to establish an analytical basis to explain how well the procedure should work. Using a stochastic approximation analytical model of the current procedure, along with computer simulation testing, the following conclusions were reached:

1. The current precision fire procedure as described in FM 6-40 is not optimal in achieving registration accuracies or target hits.

2. Using the assumptions of the current procedure, a simple alternative adjustment technique is developed. Rather than making adjustments after firing a group of rounds, a correction to firing data is made after each round is fired. This method was found to be superior to the current 6-40 procedure in the following respects:

   a. The precision fire procedure is considerably simplified.

   b. For the same ammunition expenditure, greater accuracies in adjusted registration data is achieved.

   c. The procedure is less sensitive to observer spot errors.

d. The artillery commander can tailor his registrations to the accuracy needs of his mission. The current procedure does not have this flexibility since adjusted data is based on six round groups.

e. Adjusted registration data can be further refined by considering graze bursts of time registrations.

f. For destruction purposes, approximately 10% fewer rounds are needed to attain a target hit.

3. Considerably greater accuracies can be achieved using a second alternative procedure, provided observer errors are of a certain nature. Such might be the case for an observer equipped with a laser range finder. The procedure is similar to the one discussed above in that an appropriate firing data correction is applied after each round is fired. Rather than having the observer spot OVERS, SHORTS, LEFTS, and RIGHTS, estimates of miss distances are used in the calculation. For the laser range finder equipped observer precision fire procedure, the following conclusions were reached on this alternative method:

a. The procedure is theoretically optimal under certain fairly broad conditions.

b. For an expenditure of less than half the rounds, equivalent registration accuracy with the FM 6-40 procedure is achieved.

c. The procedure minimizes the number of rounds needed to achieve a target hit. In comparison with the

current procedure, approximately 1/3 fewer rounds are needed to achieve a target hit.

d. The procedure was found to be generally insensitive to angle T, slant range, laser calibration, observer location, minor gun crew and reasonable observer lasing errors.

4. If the time to destroy a target is critical, an appropriate method of engagement appears to be by battery volley fire, rather than by single howitzer.

I. INTRODUCTION

The purpose of this thesis is to compare the current precision fire doctrine of the US Army Field Artillery with two alternate procedures; the first procedure to operate under the same system capability assumptions of the currently employed procedure, and the second to take advantage of the capabilities of observers equipped with laser range finders. In view of acquisition of new hardware, particularly the laser range finder, and statistical sampling theory developments since the inception of the current doctrine, it is hypothesized that the current precision fire procedure may not be the most accurate or economical in time and ammunition expenditure, nor the most tractable from user viewpoint in achieving desired results.

In the context of this study, precision fire will encompass only precision registration and target destruction procedures. Only the former will be subjected to a thorough analysis. Target destruction procedural comments will be general in nature and lead directly from the analysis of precision registration results.

Field artillery doctrine demands timely and accurate delivery of fire to meet the requirements of supported units in combat. To be effective, such fire must be of suitable density, accuracy and timeliness. To achieve maximum effectiveness, and the greatest demoralizing effects on the enemy,

accurately delivered massed fire without prior adjustment onto target is necessary.

To achieve the capability of accurate surprise mass fire, the target area and the howitzer positions must be surveyed on a common reference grid. Additionally, corrections for all nonstandard conditions which may affect the projectile trajectory must be found if any semblance of accuracy is to be achieved. Nonstandard conditions include such variables as small inaccuracies in survey and firing charts, atmospheric conditions, and tube wear of the cannon. To account for all errors which may result from nonstandard conditions, a precision registration is conducted.

During combat operations, fixed targets such as fortifications and bridges are encountered which may require neutralization either to impede the enemy's movements or to aid our own. Artillery in support of ground forces is the most responsive fire support means and as such is often called upon to neutralize or destroy such targets. Although prior precision of survey of the target is not essential, the requirement for precision in firing, sequential estimation of adjustment corrections to be applied during firing, and the time to achieve target neutralization is essential.

Section II will describe in basic terms the current FM 6-40 precision fire doctrine. By FM 6-40 precision fire doctrine the author implies the forward observer controlled precision registration and destruction missions as described in Chapter 19 of Ref. 14. The current FM 6-40 precision

fire procedure has been employed by the U.S. Army Field Artillery since 1941 (Ref. 16). Although the procedure has been used essentially in the same form by the field artillery for the past 32 years because it "works", it appears that no attempts have been made to justify the method statistically to explain precisely why the procedure should work and to provide an insight into some of the procedure's shortcomings. Possibly the most significant contribution of this thesis may be the development in Section III of the theoretical basis of the FM 6-40 procedure through the Stochastic Approximation Theory, first introduced by Robbins and Monro in 1951 (Ref. 12). Using this theoretical development as a base, a presentation of some major shortcomings of the current procedure is made. In addition, the theoretical foundation for a new precision fire procedure using the same system's capability assumptions as the FM 6-40 procedure is presented

Section IV describes the proposed precision fire procedure and compares the relative accuracies of precision registration data with the FM 6-40 procedure through a computer systems simulation using identical parameter inputs. In the same section a proposal is made for target destruction method when the time to achieve target destruction is critical.

Section V describes the precision fire procedure, first recommended by Grubbs in 1953 (Ref. 8), to be used if the observer is equipped with the laser range finder. Conclusions and recommendations are presented in Section VI.

II. CURRENT PRECISION FIRE TECHNIQUES

A. GENERAL

Both the precision registration and the destruction mission are characterized by two firing phases, an adjustment and a fire for effect (FFE) phase. The adjustment phase attempts to make crude estimation of the target center location by bracket halving techniques using a single howitzer firing one round at a time. The FFE phase, following an established algorithm, applies successively finer corrections to data until a predetermined number of rounds have been fired for registration correction data, or until target neutralization has been achieved. The data computed at each step of precision fire procedure, when applied to the fire control instruments on the howitzer, determine an aim point around which the rounds fired at those settings will impact. Where the rounds will actually burst depends upon the ballistic distribution pattern. The parameters of variability used by the field artillery for the bivariate normal distribution of the fall of shot are expressed in terms of probable errors in range (PER) for the range component and probable errors in deflection (PED) for the deflection component. One probable error is equivalent to .6745 standard deviations.

B. THE CURRENT REGISTRATION PROCEDURE

The base piece of the battery, normally the howitzer which is closest to the mean velocity error of all the

battery's howitzers, fires the precision registration. The registration point is a specially selected target which is readily identifiable by the forward observer (FO), centrally located within the battery target area, and permanent or semi-permanent in nature. The registration point and the base piece are located by survey.

1. Adjustment Phase

During the adjustment phase, the forward observer makes appropriate range corrections to attain successive range brackets of the target, and enters into the fire for effect phase when a 100 meter bracket in range has been achieved and halved. A bracket in range exists if and only if the last burst observed and the immediately preceding observed impact landed one short and one over the target as seen by the observer. The corrections for deviation, for those impacts occurring left and right of the target, are handled differently. In this instance the observer requests corrections to nearest 10 meters after each burst, attempting to adjust the next impact onto the observer target line.

The procedure of using bracket halving techniques to adjust for range, and adjustment to nearest 10 meters to correct for deviation, are based on the assumed forward observer capabilities in estimating burst miss distances in relation to the target if equipped only with binoculars. The underlying assumption seems to be that an observer is unable to estimate range miss distances with "reasonable accuracy" (apparently unsupported by any extensive experimentation) whereas deviation miss distances can be

estimated through the use of the mil scale in the reticle of the forward observer's field glasses. The deviation is obtained by the formula W=RM, where W is deviation in meters, R is the range to target in 1000 meter units, and M is the number of mils the observed impact occurred left or right of the target.

2. Fire for Effect Phase

During the fire for effect phase, the fire is adjusted by the fire direction center based on the observer spots of the impact of the rounds in relation to the target. The observer reports only if any single round has struck over, short, left, or right of the target. The fire direction center converts the observer burst spots from the observer target to the gun target coordinate system using appropriate tabulated conversion factors.

The procedure for estimating the target center location in range is as follows:

a. A FORK bracket is established. A FORK is the number of mils in elevation needed to move the impact of a round in range equivalent to 4PER (range probable errors). The values of FORK are tabulated for fire direction use.

b. A sufficient number of rounds are fired at the mean of the FORK bracket to achieve 3 positive fire direction range spots; that is, the 3 rounds in the gun target coordinate system must be judged to have struck over and short of the target.

c. 2 positive fire direction range spot rounds are attained at the appropriate end of the FORK bracket which is

opposite to the preponderance of overs and shorts at the FORK bracket mean. To clarify, suppose that at the mean of the FORK bracket 2 of the 3 rounds were determined to have struck short of the target. The next group of 2 rounds would be fired at that data at which a spot of over in establishing the FORK bracket was achieved.

d. The estimation of the target center location is based on the six positively spotted fire direction rounds which were fired in two groups of three rounds each at data $\frac{1}{2}$FORK apart. The appropriate correction to be applied is computed by the following "preponderance" formula:

$$\text{CORRECTION} = \frac{(\text{SHORTS} - \text{OVERS})\ \text{FORK}}{2\ (\text{NUMBER OF ROUNDS USED})}$$

where the number of rounds used is 6.

The computed correction is applied to the mean of the $\frac{1}{2}$FORK bracket at which the two groups of three rounds were fired.

The decision rules for determination of range were presented without taking into account the attainment of a target hit. A target hit is treated as a simultaneous over and short spot, but the modifications to the algorithm as a result of consideration of a target hit in any one of the phases of the registration tend to be somewhat complicated. For a complete treatment the interested reader is referred to Chapter 19, Ref. 14.

The procedures for estimating the deviation of the target center are considerably less complicated primarily due to the small PEDs encountered. In the fire for effect phase, corrections to deflection are made after each round

is spotted to have impacted left or right of the target. The correction to be applied to the initial round is a function of the gun target range and the acute angle (T) subtended by the intersection of the observer target and the gun target lines at the theoretical target center. The values of initial deflection corrections are again tabulated for fire direction center use. Successive bracket halving techniques are employed until the decision is reached that appropriate deviation corrections have been achieved. Deflection is considered correct when one of the following conditions exists:

a. there is a target hit
b. there is a split of a two mil deflection bracket
c. there are deflection spottings of left and right from two rounds fired at same deflection setting
d. there are deflection spottings of left and right from two rounds fired at deflection settings one mil apart.

Unlike the procedures for range corrections, where only the rounds in the fire for effect phase are considered, deflection correction procedure requires examination of rounds fired in the adjustment phase. If the correct deflection has not been achieved by the time range correction has, and if a deflection bracket is established, the established deflection bracket is halved to provide the adjusted deflection. If no deflection bracket exists, then a deflection bracket is "forced and half of that bracket is used as the correct deflection. One should be aware that

situations may arise, due to the angle T, where positive FDC deflection spots are difficult to achieve. The conversion tables for translating observer sensings to gun target spots do not differentiate between impacts left or right of the target. Further comments regarding this situation will be made in Section IV.

3. Adjusted Time Phase

In addition to determining corrections for range and deviation, corrections to time settings for time fuses to achieve a 0 height of burst at the registration point are desired. The procedure for estimating corrections to the time of flight in essence is a sequence of observations of time fused rounds at trial time settings to achieve a mixture of air bursts and ground bursts. The howitzer quadrant elevation employed is the adjusted quadrant elevation described in paragraph 2. Although this phase of precision registration will not be analyzed, it is mentioned because information from this phase could be employed to achieve further refinements to adjusted elevation data. The current procedure uses ground burst information only if adjusted deflection has not been achieved. Additional comments regarding this will be made in Section IV.

C. THE CURRENT TARGET DESTRUCTION PROCEDURE

The procedure for target destruction is precisely the same as described for precision registration through the attainment of the first adjusted data for range. If a deflection correction has not been attained, deflection

corrections will continue to be applied on successive rounds until the listed rules a through d previously mentioned have been met or target neutralization results, whichever occurs first. The danger of terminating consideration of deflection corrections with each round fired, if the criteria for precision registration is employed, will be discussed in the treatment of proposed procedures.

After the attainment of the first adjusted data, successive groups of six fire direction center positive range spot rounds are used to compute succeeding data corrections until the target is neutralized. Each six round group is fired at the most current adjusted elevation data. Subsequent corrections, after each six round group, are computed on the basis of the stated "preponderance" formula:

$$\text{CORRECTION}=(1/n)\,\frac{(\text{SHORTS-OVERS})\ \text{FORK}}{(2)\ (6)}$$

where 'n' indicates the nth adjusted data correction or the nth six round group considered. Note that the adjusted data for the precision registration was computed with n equal to 1. If after the fourth iteration a target has not been neutralized, n retains the value of 4 for each succeeding six round group refinement.

III. THEORETICAL BASIS FOR CURRENT PRECISION FIRE PROCEDURES

This section will analyze the theoretical basis for the current precision fire procedure as outlined in FM 6-40 (Ref. 14), and provide a theoretical foundation for proposed modifications. Only those portions pertaining to the estimation of range corrections will be treated. In comparison with range errors, deflection errors are nearly always insignificant, with the ratio of probable error in range (PER) to the probable error in deflection (PED) on the order of 7 to 1. No proofs will be given. Verification of specific results quoted from literature was accomplished through Monte-Carlo computer simulations. Since the final results of this thesis will, for the most part, be based on direct computer simulation comparisons of all competing procedures, computer verification of literature provides the basis for the validity of the computer models employed. For those readers interested in full analytical developments of results quoted, references will be listed.

Those familiar with stochastic approximation theory and the published works of Robbins and Monro (Ref. 12), Block (Ref. 2), Chung (Ref. 4), Hodges and Lehman (Ref. 9), and Cochran and Davis (Ref. 5) will readily recognize the quoted "preponderance" formula as being the Robbins-Monro Stochastic Approximation Technique using a six round sample at each level considered to estimate the .5 quantile response level.

In terms of artillery precision fire it is the estimation of that data which when applied will cause any round fired to have equal probability of striking over or short of the target center. If the aim point data corresponding to the mean of the normal ballistic distribution can be made to coincide with the theoretical target center, then all corrections to nonstandard conditions will have been achieved. Furthermore, this data will also provide the maximum single shot hit probability of a target. The probability of achieving a hit on a target for any given normal ballistic distribution is directly dependent on the actual aim point location; the closer the aim point or the mean of the ballistic distribution is to the target center, the greater the probability of attaining a hit on that target.

Robbins and Monro (Ref. 12) introduced a method of stochastic approximation for estimating any L_p, the level at which the probability of attaining a "positive response" is p. In terms of artillery precision fire, the positive response is a gun-target line OVER spot, and L_p corresponds to the howitzer elevation setting at which the probability of attaining an OVER spot is p. A series of observations y_n is taken at levels x_n such that after n trial observations the n+1st estimate of L_p is determined recursively by

$$x_{n+1} = x_n - a_n(y_n - p)$$

where:

$$y_n = \begin{cases} 1 \text{ if nth observation is "positive response" (OVER)} \\ 0 \text{ if otherwise} \end{cases}$$

a_n = an appropriate sequence of positive constants

x_n = the level (howitzer elevation) at which y_n was attained

If y_n is one, the next observation is taken at a lower level, and if y_n is zero, the next observation is taken at a higher level. The constants a_n are chosen to depend on n such that successive changes of level become smaller and the estimates of L_p converge to the true value of L_p.

Block (Ref. 2) proposed a modification of the Robbins-Monro iterative procedure by recommending that instead of taking a single observation at each level, the same results may be obtained by taking several observations at any single level before making a correction in the estimation of L_p. The idea is that it may cost less to take several observations at any one point than the same number of observations at different points. If the procedure were to be used in bioassay to estimate LD_{50}, (the lethal dose which would on the average produce 50% deaths), of a particular drug on a number of laboratory animals, then time would be saved if several animals could be given the drug at a particular dosage level simultaneously since the effects of the drug tested may take some time to achieve a reaction from the animals. However, as will be noted later, taking several samples at a single level could produce adverse effects in estimating LD_{50} if the total sample size is small.

The method described by Block for estimation of LD_{50} in bioassay with more than one animal at any level is precisely

the same as used by the current precision fire procedure in estimating firing data which would place the mean of the ballistic distribution at the actual target center. In terms of the artillery problem, Block's modification of Robbins-Monro recursive form for the $(n+1)^{st}$ approximation of the target center firing data may be defined inductively by the following formula:

$$X_{n+1}=X_n-a_n\left(\frac{\sum_{i=1}^{6} Y_i^n}{6}-\tfrac{1}{2}\right)$$

where:

X_{n+1} = the $(n+1)^{st}$ approximation of the target center aim point

X_n = the n^{th} approximation of the target center aim point

a_n = a suitably chosen set of constants, in this case FORK/n

Y_i^n = the i^{th} observation at the n^{th} trial where

$$Y_i=\begin{cases}1 \text{ if impact observed to strike over target}\\ 0 \text{ if impact observed short of target}\end{cases}$$

To show that the Robbins-Monro recursive form as described by Block with a_n=FORK/n provides the same results as the FM 6-40 "preponderance" formula, consider the following example. Let us assume that as a result of firing a six round group at a quadrant elevation of 300 mils, 4 rounds were observed to impact over and 2 short of the target. Let us further assume that this is the second six round group and the value of FORK is twelve mils. The data to fire the

third six round group using the Robbins-Monro and the FM 6-40 preponderance formula is as follows:

1. Robbins-Monro Method

$$\text{NEW ELEVATION} = \text{FIRED ELEVATION} - \frac{\text{FORK}}{2}\left(\frac{4}{6} - \frac{1}{2}\right)$$

$$= 300 - \frac{12}{2}\left(\frac{1}{6}\right)$$

$$= 299 \text{ mils}$$

2. FM 6-40 Preponderance Method

$$\text{NEW ELEVATION} = \text{FIRED ELEVATION} + \frac{(\text{SHORTS}-\text{OVERS})}{(2)(6)}\frac{\text{FORK}}{2}$$

$$= 300 + \frac{12}{24}\,(-2)$$

$$= 299 \text{ mils}$$

Any other combination of overs and shorts will produce identical results for both recursive forms. To see this, let's rewrite the two correction formulas in terms of OVERS and SHORTS. Recalling that Robbins-Monro inductive correction formula considers only OVERS, we want to show that for any number of rounds considered, equality is retained. We'll start with the Robbins-Monro form:

$$\frac{-\text{FORK}}{n}\left(\frac{\#\text{OVERS}}{\#\text{OBSERVED}} - 1/2\right) = \frac{-\text{FORK}}{n}\left(\frac{2(\#\text{OVERS}) - \#\text{OBSERVED}}{2(\#\text{OBSERVED})}\right)$$

since #OBSERVED = #OVERS + #SHORTS, we get

$$\frac{-\text{FORK}}{n}\left(\frac{\#\text{OVERS} - \#\text{SHORTS}}{2(\#\text{OBSERVED})}\right) \qquad \frac{\text{FORK}}{n}\left(\frac{\#\text{SHORTS} - \#\text{OVERS}}{2(\#\text{OBSERVED})}\right)$$

and this is the FM 6-40 preponderance formula.

Having shown that the method of precision fire as described in FM 6-40 is the Robbins-Monro type multisample technique for determination of the .5 quantile response level, properties developed for the Robbins-Monro procedure will be applicable to precision fire procedure. The

theoretical results which are to be presented were extracted from Cochran and Davis (Ref. 5), except where noted and where modified by the author to make them applicable to the artillery problem.

The conditions under which the estimates of the mean aim point converge to the actual mean (the true target center) in mean square with probability 1 are discussed by Robbins and Monro (Ref. 12), Wolfwitz (Ref. 13), Blum (Ref.3) and Kallianpur (Ref. 11). Hodges and Lehman (Ref. 9), extending the findings of Chung (Ref. 4) who investigated the asymptotic convergence of the Robbins-Monro procedure, recommend that the recursive constant to be used in the quantal response problem should be $a_n=c/n$.

Following is a set of results quoted from Cochran and Davis (Ref. 5) regarding the asymptotic distribution of the estimates which are pertinent to our analysis:

1. The estimate of the actual target center $\hat{u}$ becomes normally distributed about the actual target center u with variance $c^2/4mn(2cf-1)$ where f is the ordinate of the underlying normal ballistic distribution at its median, n is the n^{th} level, and m the number of samples observed at each level. For the above relationship to hold, it is required that c be greater than $\frac{1}{2f}$.

2. From 1 above, then, the best step size c in terms of asymptotic convergence properties should be $c=1/f$, giving a minimum variance of $1/4mnf^2$.

3. For the normal underlying distribution $f=\frac{1}{\sigma\sqrt{2\pi}}$, which leads to the result that the optimum step constant

should be $c=\sigma\sqrt{2\pi} = 2.506\sigma$. With this step constant the variance of the estimate of the target center after n trials and m observations at each trial equals $\pi\sigma^2/2mn$.

4. Not using the optimum step constant c but using another step constant c' has the effect of multiplying the minimum asymptotic variance by a factor of $r^2/(2r-1)$, where $r=c'/c$.

5. the distribution of the estimated target mean about the actual target center location, after n trials and m observations at each trial, will tend to be normally distributed $N(0,\frac{r^2\pi\sigma^2}{(2r-1)2nm})$ where σ^2 is the round to round variance fired at the fixed elevation corresponding to the estimated target center location.

using results 1 through 5, the accuracy of the current registration procedure can now be analyzed. A measure of accuracy often used to assess the capability of an artillery procedure is the expression of the expected absolute miss distance as a function of the probable error in range (PER). For the current registration procedure the parameter values applied to the theoretical distribution of the estimated target center location are, $r^2/(2r-1)=1.005$, $n=1$, and $m=6$, where m is the number of rounds used to estimate the corrections to be applied to place the aim point at the target center location. To see that $r^2/(2r-1)=1.005$, recall that the step constant used in the current precision fire procedure is 1 FORK. 1 FORK = 4 PER; 1 PER = $0.6745\sigma \Rightarrow$ FORK = $2.7\sigma \Rightarrow r = 2.7/2.506 \Rightarrow r^2/(2r-1) = 1.005$, concluding that for all practical purposes the current procedure

uses the optimum step constant. Reviewing briefly the procedures employed in the fire for effect phase, the following steps are taken:

1. A FORK bracket is established

2. Three rounds are fired at the mean of the established FORK bracket.

3. Based on the number of rounds which impacted over or short in 2, two additional rounds are fired at the appropriate FORK bracket data which is opposite to the preponderance of overs and shorts.

4. The "preponderance" formula is applied to the mean of the $\frac{1}{2}$ FORK bracket at which the two groups of three rounds were fired. The assumption is that the two groups of three rounds $\frac{1}{2}$ FORK apart may be treated as if all six rounds were actually fired at the mean of the $\frac{1}{2}$ FORK bracket. Treating the two groups of three rounds as if all six were fired from the mean of the $\frac{1}{2}$ FORK bracket has the effect of increasing the round to round variance by $(\mathrm{PER})^2$; this follows directly from the fact that the mean of the $\frac{1}{2}$ FORK bracket is 1 PER removed from the aim points of the two groups of three rounds fired at the ends of the $\frac{1}{2}$ FORK bracket. The actual variance instead of being σ^2 is now $\sigma^2+(\mathrm{PER})^2$. Recalling that $.6745\sigma = \mathrm{PER}$, the effective variance in terms of PER becomes

$$\mathrm{VAR}_{\mathrm{eff}} = 3.1980\ \mathrm{PER}^2.$$

With this effective variance, the variance of the aimpoint distribution after the completion of firing is

$$\mathrm{VAR}_{\mathrm{aim}} = \frac{\pi}{2(6)}\ 3.1980\ \mathrm{PER}^2 = 0.8372\ \mathrm{PER}^2.$$

The expected absolute miss distance can be calculated by using the relationship that $E^2(|X|) = (2/\pi)V(X)$ where $E^2(|X|)$ is the expected absolute value of X, squared, and V(X) is the variance of X. The expected absolute miss distance (ABS MEAN) in terms of PER is then,

$$\text{ABS MEAN} = \sqrt{2/\pi\,(0.9372)\,\text{PER}^2}$$

$$= 0.7301 \text{ PER.}$$

Accounting for use of non-optimal step size,

$$\text{ABS MEAN} = 0.7317 \text{ PER for all PER.}$$

The conclusion then is that the mean absolute miss distance in range achieved as a result of the current FM 6-40 procedure is 0.7317 PER for all PER fired. Ref. 17, conducted by the Gunnery Department, U.S. Army Field Artillery School, calculated the absolute mean miss distance to be 0.6558 PER. A close scrutiny of the method employed in achieving the analytical results reveals that error may have been committed because of the nature of discrete approximation used in that study. Computer simulation analysis based on 1000 and 10000 replications of the current registration procedure using PER values of 7, 13, 20, 27, and 34, gave a range for the absolute mean miss distances of 0.725 to 0.735 PER.

In their investigation of the Robbins-Monro technique for the estimation of the mean lethal dose (LD_{50}) of a drug, Cochran and Davis discuss the performance of the procedure if only a small experimental sample size is used. Since the asymptotic properties of the Robbins-Monro procedure (for large n) are well documented in literature, they wanted to

know how well the technique would work if n were 50 or less. The questions they sought to answer, pertinent to the study of the precision fire procedure as described in FM 6-40, were the following:

1. Do the asymptotic properties ascribed to the Robbins-Monro procedure hold if the sample size used is small? In other words, does the distribution of the estimate of the mean about the actual mean continue to behave as though it were normally distributed $N(0,\frac{\pi\sigma^2}{2nm})$ when the "optimal" step constant is used ($C = 2.506\sigma$)?

2. How sensitive is the asymptotic behavior to the selection of a non-optimal step constant?

3. Given a small experimental sample size, what precision in the estimate of the mean can one expect if one, two, or more samples are examined at each level?

4. How sensitive is the accuracy of the estimate to errors of the initial start point? In other words, how far away from the true mean can the initial estimate for the Robbins-Monro process be and still continue to provide accurate results?

Although precise mathematical methods were employed by Cochran and Davis, the results to be listed here are based on the author's analysis through computer simulations for reasons already cited. Computer simulations of relevant applicable portions of the referenced study were in agreement. For comparison purposes, two procedures were analyzed. Procedure #1 (P1), the current FM 6-40 procedure

already described; procedure #2 (P2) using six rounds with one round considered at each of the six levels.

A. EFFECTS ON ASYMPTOTIC CONVERGENCE OF SIX ROUND SAMPLE WITH OPTIMAL STEP CONSTANT

1. Procedure P1

AVERAGE ABSOLUTE MISS DISTANCE = 0.730 PER

PREDICTED = 0.730 PER

2. Procedure P2

AVERAGE ABSOLUTE MISS DISTANCE = 0.620 PER

PREDICTED = 0.608 PER

The difference in magnitude of results between P1 and P2 should not be surprising; the effects of treating the two groups of three rounds fired 1.753σ (approx. $\frac{1}{2}$ FORK) apart as if six rounds were fired at the mean of the 1.753σ bracket have been discussed.

B. EFFECTS OF USING A STEP CONSTANT TWICE THE OPTIMUM STEP SIZE

Only procedure P2 is considered.

AVERAGE ABSOLUTE MISS DISTANCE = 0.709 PER

PREDICTED = 0.699 PER

As was stated, doubling the optimum step size has the effect of increasing the variance of the estimate of the mean by $r^2/(2r-1)$ where r equals the ratio of step constant used to optimum step constant. The average absolute miss distance is increased by $r/\sqrt{(2r-1)}$.

C. EFFECTS OF USING ONE ROUND AT SIX LEVELS AS COMPARED TO SIX ROUNDS AT ONE LEVEL

Within a specified range of starting values, no significant difference exists between one round and six levels, or six rounds and one level, provided the six rounds at one level are based on a "true" group of six rounds observed originated from the same setting.

D. EFFECTS OF STARTING POINT ON ACCURACY OF THE ESTIMATE

In the context of this study, a starting point may be defined as the initial estimate point at which the computational Robbins-Monro algorithm begins to be applied. For procedure P1 the start point corresponds to the mean of the $\frac{1}{2}$ FORK bracket at which the two groups of three rounds were fired; for P2 it is that point corresponding to the first round at which the Robbins-Monro recursive formula is applied. A "stable region" will be used to describe the range of the starting points within which the average absolute miss distance remains nearly constant.

1. Procedure P2

The stable region for procedure P2 using the optimum step constant ($C = 2.506\sigma$) extended to approximately 3.5 PER. At 4.5 PER the average absolute miss distance deteriorated by 20%, and 110% at 6 PER. Using a step constant twice the optimum ($C = 5.012\sigma$) extended the stable region to approximately 8.5 PER.

2. Procedure P1

The stable region for the current procedure was relatively short, extending to 2 PER. Accuracy

deteriorated by 20% for start point at 2.5 PER, 50% at 3 PER, and 200% at 4.5 PER. However, within the stable region, unlike procedure P2, P1 showed some accuracy improvement (8%) at 1.5 PER; the slight improvement recorded is in agreement with Cochran and Davis' findings using six samples at each level.

Of the procedures investigated, P2 with twice the optimum step constant was by far the most robust; the price for almost tripling the stable region by doubling the optimum step constant is approximately a 15% loss in the estimate of the actual target center location in terms of absolute average miss distance. P1 is very sensitive to the distance of the start point in relation to the target and deteriorates quite rapidly when start points are more than 2 PER removed.

Because of the large biases observed when the start point is outside the stable range, Cochran and Davis suggested a modification to the Robbins-Monro process in which the step constant remains equal to C until both overs and shorts are observed to provide a high assurance that the first iterative application of the recursive formula is within the stable range. The current precision fire procedure does precisely that, although in a slightly modified form, to attain a high probability of applying the "preponderance" formula within a 2 PER range of the true target center location. The "efficiency" of the FM 6-40 algorithm, if no errors in sensing over and short rounds

are committed, is attested to by the consistency of correspondence of computer simulation test results with those theoretically predicted. What perhaps is even more significant, the methods described for the current precision fire procedure predate the Robbins-Monro papers by 10 years, and the "optimality" conditions described by Cochran and Davis for practical applications of stochastic approximation theory for small samples by 22 years. Unfortunately, the records of the origins of the current registration procedure (Ref 16) do not contain a discussion of the theoretical basis. Additionally, the author has not been successful in his efforts in locating any subsequent theoretical documentation for the current procedure, for apparently none exists. The procedure, essentially unchanged for 32 years, has been accepted because it "works". The reasons why the procedure works, along with some of its shortcomings, have been discussed.

IV. PROPOSED PRECISION FIRE PROCEDURE FOR FORWARD OBSERVER EQUIPPED ONLY WITH FIELD GLASSES

A. GENERAL

Only the basic essential rules for the current FM 6-40 procedure have been discussed in Section II. The procedure in actual employment tends to be more complex due to other considerations. These considerations deal with target hit treatments, accounting of all over and short spots, and verification of data if a registration is considered to be suspect. If a target hit is attained in the adjustment phase, the requirement for establishing a FORK bracket is dispensed with. If a target hit occurs in establishing a FORK bracket, the establishment of a FORK bracket is no longer required. If a target hit is attained during any other portion of the fire for effect phase, it is treated as an ordinary round. In all cases, a target hit is considered as a simultaneous over and a short round. The logic behind dispensing with establishment of a FORK bracket with a target hit is sound. If a target hit is attained, the probability that the mean of the ballistic distribution is within 1 FORK (2.7σ), is $P=0.993$. Because of the critical requirement that the mean of the ballistic distribution, at which the "preponderance" formula is applied, be within 2 PER of the actual target center (see Section III), a registration which gives a combination of 5 and 1 of over and

short spots has to be treated as suspect and normally requires "verification" firing of additional rounds. For precise procedure, refer to Chapter 19, FM 6-40.

Because of lack of understanding of the underlying basis of the current procedure and the "complexities" of special situations (based on author's own field artillery experience), the field user tends to simplify these rules. For example, target hits are being treated as if two rounds were fired. The "logic" used is that with a target hit an over and a short spot is attained, and is equivalent to two fired rounds; this leads to inaccuracies because the preponderance formula has a six round base. Cases also arise, although rare, where 5 and 1 combinations of overs and shorts are being "forced" into 4 and 2 spot combinations to avoid verification. The procedure of forcing a registration has substantial effects on the accuracy of adjusted data. Computer simulation results, based on 1000 replications of the current procedure, show that if the spot of a round fired at the mean of the FORK bracket is changed, the accuracy of the adjusted data in terms of absolute miss distance will be 45% worse than if the spot was not changed. Changing a spot of the second group of three rounds (those fired at either end of the FORK bracket) produced an average decrement in accuracy of 35%. The reason for a greater decrement if a spot at the FORK mean is changed before firing the second group of two rounds should be obvious, for these spots are used to determine the $\frac{1}{2}$ FORK (2PER) bracket

of the target. A changed spot will move the aimpoint at which the preponderance formula is applied outside the 2 PER stable region (discussed in Section III) where rapid deterioration occurs. A lesser effect on accuracy deterioration occurs if the spot of one of the last two rounds fired at the appropriate end of the FORK bracket is changed. The appropriate $\frac{1}{2}$ FORK (2PER) bracket is established, but the correction to be applied by the preponderance formula is not appropriate. For example, suppose FORK=12 mils, and that a change in elevation of 1 mil corresponds to 10 meters in range. As a result of the registration, 5 overs and 1 short were recorded, but because of unwillingness to verify a 5 and 1 registration the last round spot of over is changed to a short to give a 4 and 2 registration. The correction which should have been applied with 5 overs and 1 short is (12/24)(1-5)=-2 mils; with a 4 and 2 spots this correction becomes (12/24)(2-4)=-1 mil. Changing a 5 and 1 to 4 and 2 resulted in a 10 meter error in estimating the corrections needed to place the mean of the ballistic distribution over the actual target center. Although other factors may be involved, the implications of the practice of changing a spot to attain "desired" results should be clear.

Based on the author's artillery experiences, the "field modifications" of the current registration are a direct result of the non-intuitive appeal of data adjustment procedure algorithm used in the fire for effect phase,

along with the accounting procedures for the over and short spots and the precise, often misunderstood, procedural rules which must be strictly adhered to if accuracy in adjusted data is to be achieved.

In Section III, the author presented some significant results of using a one round base to determine the sequential corrections to estimate the target center location. These were:

1. Making a correction after spotting of each round extended the stable region to 3.5 PER when the optimal step constant is used.

2. Using a one round base with twice the optimal step constant extended the stable range to 8.5 PER at a cost of 15% reduction in accuracy as measured in terms of average absolute miss distance, but equivalent in accuracy to the current precision fire procedure, and superior to the current FM 6-40 procedure in the size of the stable region. The stable region of the current procedure was shown to be 2 PER.

A procedure which is based on appropriate sequential corrections to move the impact to the target after each round is fired should prove to be less confusing and of greater intuitive appeal to the field user than the current procedure. In addition, a precision fire procedure which makes successive corrections after each round is fired rather than waiting until six rounds have been expended would increase the probability of achieving a target hit if

used for target destruction, in the sense that the probability of achieving a hit is directly dependant on the round to round variance and the location of the mean of the bivariate normal ballistic distribution in relation to the true target center.

B. THE PROPOSED PRECISION FIRE PROCEDURE

Based on the results of analysis in Section III and the preceding discussion, the one round Robbins-Monro based recursive technique with a FORK base is recommended for precision fire procedure.

1. Basic Assumption

The basic underlying assumption is that the best information about round impacts one can reasonably expect from a forward observer equipped only with field glasses are his primary quadrant spottings of bursts in relation to the target. In other words, he is only capable of spotting accurately if a round impacted over, short, left or right of the target. This assumption is the same as for the current precision fire procedure.

2. Description of the Procedure

The proposed procedure is divided into two phases, an adjustment and a fire for effect phase. The adjustment phase is to be conducted in the same manner as for the current registration procedure by entering into fire for effect phase when a 100 meter bracket in range is split. In the fire for effect phase, a correction is made after each fire

direction positively spotted round until the specified number of rounds have been fired for the determination of final adjusted data.

a. The Fire For Effect Phase Range Corrections

A correction for range is applied after every fire direction center positively spotted range round (all OVER and SHORT spots). The correction is applied in opposite direction of the spot; that is, if the fire direction range spot is OVER, the calculated correction is subtracted from the quadrant elevation at which the round giving an OVER spot was fired. In general the recursive algorithm for calculation of corrections for range is:

$$\text{CORRECTION} = \frac{\text{FORK}}{n}\,(Y)$$

where: $$Y = \begin{cases} -1 & \text{if FDC range spot is OVER} \\ +1 & \text{if FDC range spot is SHORT} \end{cases}$$

n = the n^{th} effective positively sensed range round

The correction for first fire for effect positively spotted range round is to be FORK/k where k represents the number of rounds considered from the adjustment phase, specifically:

k = 1 for all FFE PERs less than 9 meters
= 2 for all FFE PERs between 9 and 18 meters
= 3 for all other PERs

After establishing an initial FORK/k bracket, k is advanced by 1 for each subsequent positive range round until the mission is terminated.

(1) The Choice of FORK as Recursive Constant

FORK, in the manner used in the recursive formula is equivalent to 2.15 C_o, where C_o is the optimal

step constant discussed in Section III. FORK was chosen for two reasons. First, the stable range is a little greater than 8.5 PER permitting the use of information which is available from the rounds fired in the adjustment phase. Secondly, the FORK step constant, as opposed to 3/4 or 1/2 FORK, proved to be less sensitive to observer errors in judging whether a round impacted over or short of the target when the probability of such errors exceeded P=0.05.

(2) The Choice of k, the Effective Initial FEE Round Number

Using FORK as the recursive step constant permits utilizing information which is available from the adjustment phase, in particular those rounds used in establishing and halving the 100 meter bracket. As an example, let us assume that the fire for effect PER = 25 meters. Since FORK = 4 PER, this implies FORK = 100 meters; since PER is greater than 18 meters, k=3. By establishing a 100 meter bracket and then making an appropriate 50 meter shift to enter into the fire for effect phase, in effect the algorithm has already been applied twice, and the next correction to be made should be FORK/3. That this decision rule works for all angle Ts will be shown in paragraph D,5, of this section.

(3) Establishing the Initial FORK/k Bracket

Based on extensive computer simulation testing when forward observer spotting error probability exceeds 5%, it was found desirable to establish an initial

FORK/k bracket for PERs less than 18 meters. For the sake of uniformity, FORK/k bracket is retained for all PERs. The additional cost in ammunition expenditure for establishing the initial FORK/k bracket averaged out to approximately 0.5 rounds more than required by the current procedure in establishing the initial FORK bracket. The figure 0.5 rounds is misleading, since the ammunition expenditure for the current FM 6-40 procedure is based on the average number of rounds needed to attain adjusted data (as generated by computer simulation model) EXCLUDING all 5 and 1 registrations. If verification of 5 and 1 registrations was resorted to by considering additional rounds, the difference in ammunition expenditures should have been non-existent. Additional comments regarding ammunition expenditures will be made in part D of this section.

b. Fire For Effect Phase Range Corrections - User Information

(1) The gunners quadrant is to be used for setting quadrant elevation for all rounds fired in the fire for effect phase.

(2) All corrections are to be computed to the nearest 0.1 mil.

(3) All quadrant elevation settings will be to the nearest 0.1 mil.

(4) With the exception of those positive spotted range rounds used in establishing the initial bracket, no track or accounting of previously attained positive range

rounds is needed. The corrections are based STRICTLY on the spotting of the LAST round fired.

(5) Target hit considerations are, if a target hit occurs prior to establishing the initial FORK/k bracket, that bracket need not be established. Whenever a target hit occurs, k is advanced by one; the next round is fired with the same data as the round which was sensed to be a target hit. In other words, a correction is not computed.

(6) If an FDC doubtful range spot is attained, k is not advanced by one unit, but the round is refired as is the practice with the current procedure. K is advanced only when a fire direction center positive range round is obtained.

A comprehensive example of the computational procedure applying the above stated rules is presented in Appendix B.

c. Deflection Corrections

The adjusted deflection is derived in the same manner as for the current procedure with following important modifications:

(1) A deflection is NOT considered correct until the last round in the fire for effect phase has been fired, even if a two mil deflection bracket is split, a target hit is attained, or left and right spots are obtained at the same deflection settings or at settings 1 mil apart. If a deflection is determined to be "correct" using the criteria for the FM 6-40 procedure, a 1 mil correction in

deflection is to be made for EACH subsequent fire direction center deviation spot until the firing is completed. This procedure is especially critical for target destruction missions, if such targets are smaller than 20 by 20 meters. On the basis of target destruction simulation runs, it was discovered that on occasions the mean of the ballistic distribution, as a result of considering deflection correct, was established excessively too far to the left or right of the target, resulting in an inordinate number of rounds (several hundred) to achieve a target hit.If it is deemed impractical to apply 1 mil deflection corrections with each positively spotted deviation round, then a rule to apply the appropriate 1 mil deflection correction after two or three successively spotted deviation rounds of the same spot (either all left or all right) is recommended.

(2) If, after completion of firing the specified number of positively spotted range rounds to compute the adjusted elevation, and consideration of all graze bursts during the time adjustment portion, the "correct" deflection has not been achieved, consider the deflection correct. Simulation results showed that firing additional rounds to achieve correct deflection as described in FM 6-40 results in needless expenditure of ammunition without improvement of adjusted deflection data.

d. Refinement of Adjusted Range Data from Graze Bursts in Time Registration Portion

Under current doctrine, information from graze bursts (those bursts occuring on the surface) during the

time registration portion are used in instances when adjusted deflection has not been determined; no attempt is made to use this information to refine adjusted elevation. Since the elevation used to fire all rounds in time registration is the adjusted elevation determined as a result of firing described in (a), an appropriate correction to the adjusted elevation should be made based on the difference of OVER and SHORT graze bursts in accordance with the following correction formula:

$$\text{CORRECTION} = \frac{\text{FORK}}{n+m}\ (\text{SHORTS-OVERS})$$

where n corresponds to the last integer used to compute adjusted elevation correction, and m is the number of positive range spots from graze bursts. Appropriate fuze setting adjustments as a result of this refinement should not present problems.

C. INITIAL CONPARISON OF FM 6-40 AND RECOMMENDED ROBBINS-MONRO ONE ROUND PROCEDURE

1. General

An initial analysis of both competing procedures was conducted by means of a simplified Monte-Carlo computer simulation. Documentation of computer program used may be found in Appendix E.

2. Purpose

The purpose of the simplified model, in addition to approximating theoretical results which should be achieved under no error assumptions, was to isolate those forward observer spot errors which may have the greatest effect

upon the accuracies of the competing procedures. Answers to the following question were sought: if forward observer errors in spotting over and short bursts occur with a probability greater than zero in any one phase of the precision registration, what effects do those errors have in the accuracies of determined adjusted data of both procedures?

3. Brief Description of Model and Assumptions

a. Only the algorithms for estimating range corrections are used.

b. Both an adjustment and a fire for effect phase are modeled.

c. For both procedures, the initial burst location at the start of each mission is randomly generated within 200 meters of the true target center location.

d. Doubtful range is not modeled.

e. No target hits are possible, only a theoretical target center is considered. This implies that every burst generated will be either over or short of the hypothetical target center.

f. All range corrections requested are precisely given; that is, if a correction of 23.14173 meters is called for, that precise correction is given.

g. PER = 20 is used for both procedures.

4. The Results

The results to be presented are based on 1000 computer simulation replications. Data results are presented in graphical form. The accuracy of the estimate of the

true target center after completion of registration is expressed in terms of the absolute miss distance in PER as a function of observer probability of spot error. The Robbins-Monro one round technique is abbreviated as RM. Round numbers associated with the RM procedure correspond to the effective fire for effect rounds used in determining the adjusted data. For example, RM-6 is equivalent to firing the same number of fire for effect rounds as for the current FM 6-40 procedure: RM-3 implies firing three rounds less than the current procedure.

a. No Error Results

The data from this section are displayed as the initial plots on all graphs. The no-error results will be compared to accuracies which should have been achieved using the asymptotic theory as developed in Section III. The predicted results in terms of expected absolute miss distance as a function of PER for the Robbins-Monro procedure using a 2 FORK recursive step constant are given by solving the following equation:

$$\text{EXPECTED ABSOLUTE MISS DISTANCE} = \sqrt{\frac{2}{\pi}\,\frac{r^2}{2r-1}\,\frac{\pi}{2(n+k)}\,\left(\frac{\text{PER}}{.6745}\right)^2}$$

where: n = the effective fire for effect round number

k = the number of rounds which are used from the adjustment phase

r = (step constant used)/(optimum step constant) where optimum step constant = 2.506

For the current FM 6-40 procedure, the expected absolute miss distance equation was developed in Section III and is:

$$\text{EAMD} = \sqrt{\frac{2}{\pi}\ \frac{r^2}{2r-1}\ \frac{\pi}{(2)(6)}\ ((\frac{\text{PER}}{.6745})^2 + (\text{PER})^2}$$

The comparative results are as follows:

(1) RM-3 Round Procedure

PREDICTED RESULTS = 0.717 PER

SIMULATION RESULTS = 0.740 PER

(2) RM-4 Round Procedure

PREDICTED RESULTS = 0.664 PER

SIMULATION RESULTS = 0.662 PER

(3) RM-6 Round Procedure

PREDICTED RESULTS = 0.586 PER

SIMULATION RESULTS = 0.590 PER

(4) FM 6-40 (6 Round Procedure)

PREDICTED RESULTS = 0.732 PER

SIMULATION RESULTS = 0.730 PER

Results from this analysis indicate that the computer simulation parallels closely the results predicted by use of asymptotic theory with exception of RM-3 round procedure where a difference of approximately 3.2% occurred.

b. Effects of Observer Errors in Establishing the Initial Fire for Effect Bracket

Figure 1 depicts the accuracy attained if the forward observer commits errors in spotting only those rounds which are used in establishing the initial fire for effect bracket. For the FM 6-40 procedure this corresponds

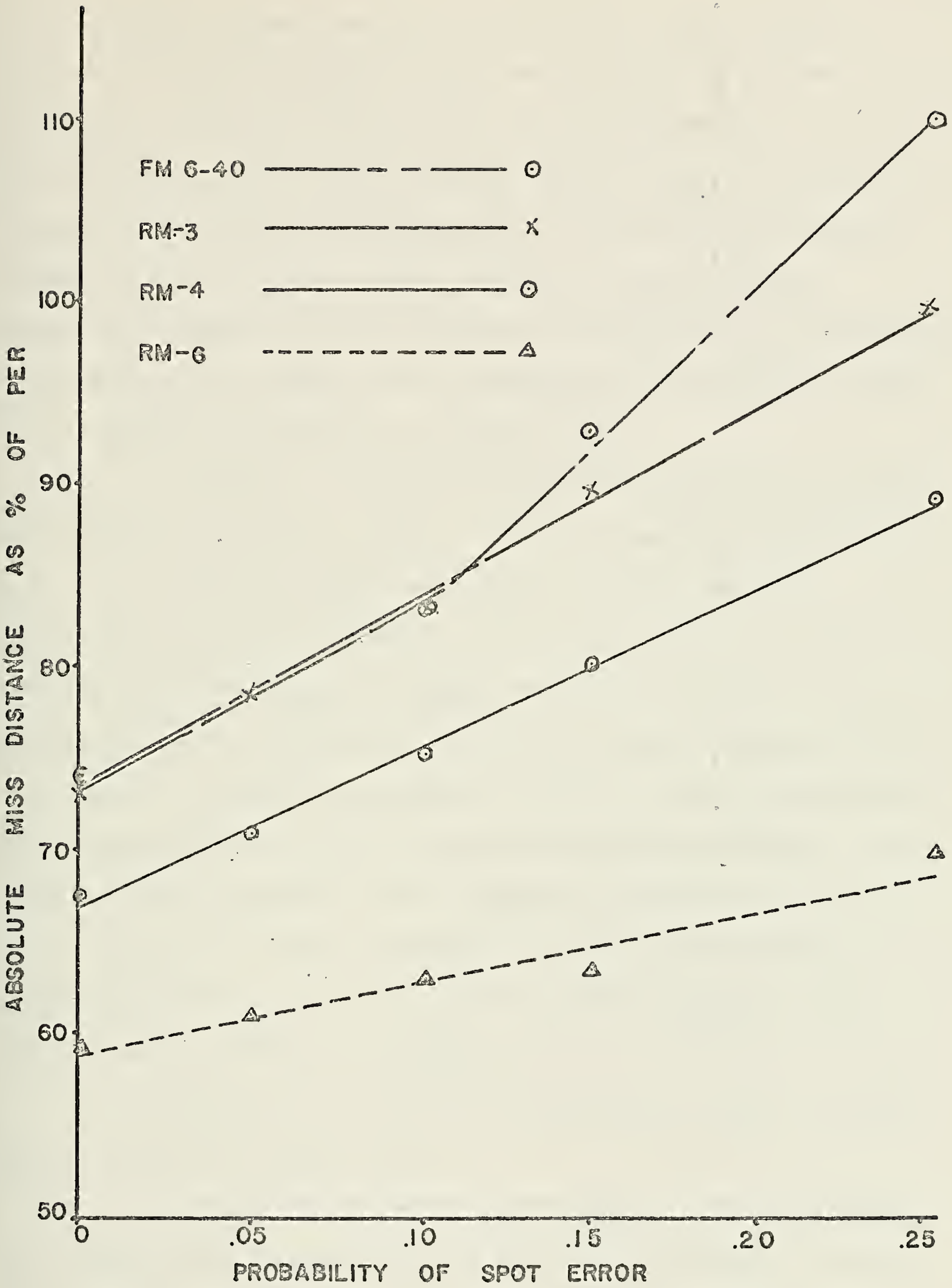


Figure 1 - Effects of Errors in Establishing Initial Fire for Effect Bracket

to the FORK bracket, and for the RM the initial FORK/k bracket. Results indicate that the six round proposed procedure is least affected by the initial bracket errors, deteriorating 15% in accuracy for 25% spot error probability whereas the current procedure results deteriorated approximately 35%. The three round version of the proposed procedure appears to be as accurate as the current procedure in lower range of spot error probability, but clearly superior when error probability exceeds 12.5%.

c. Effects of Forward Observer Errors if Such Occur Only After the Initial Fire for Effect Bracket is Established

Figure 2 depicts results of the competing procedures under the condition that the observer spotting errors will occur only on those rounds fired after the initial fire for effect bracket is achieved. Results indicate that the current procedure, RM-6, and RM-4 deteriorated in accuracy whereas RM-3 remained relatively unchanged. The greatest deterioration, when compared to bracket error effects, occured in RB-6 procedure. RM-3 round procedure achieved better accuracy than the current procedure when spot error probability exceeded 5%.

d. Effects of Errors if Such Errors Occur Over the Entire Fire for Effect Phase

Figure 3 presents the results of the competing procedures when subjected to spot errors throughout the entire fire for effect phase. Results again indicate the overall superiority of the proposed RM-3 round, 4 round and 6 round versions over the current FM 6-40 procedure.

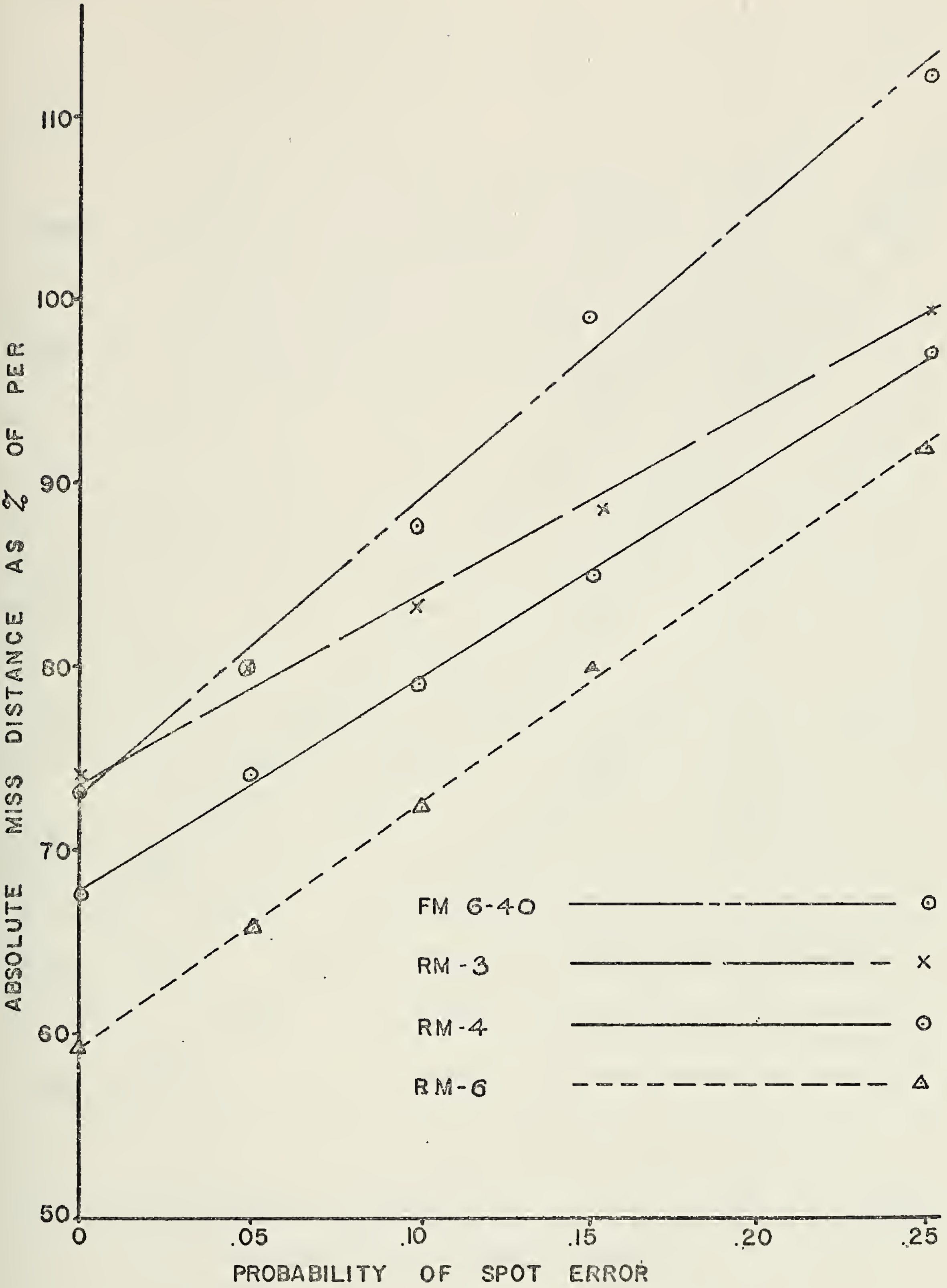


Figure 2 - Effects of Errors on Rounds after Initial Fire for Effect Bracket is Established

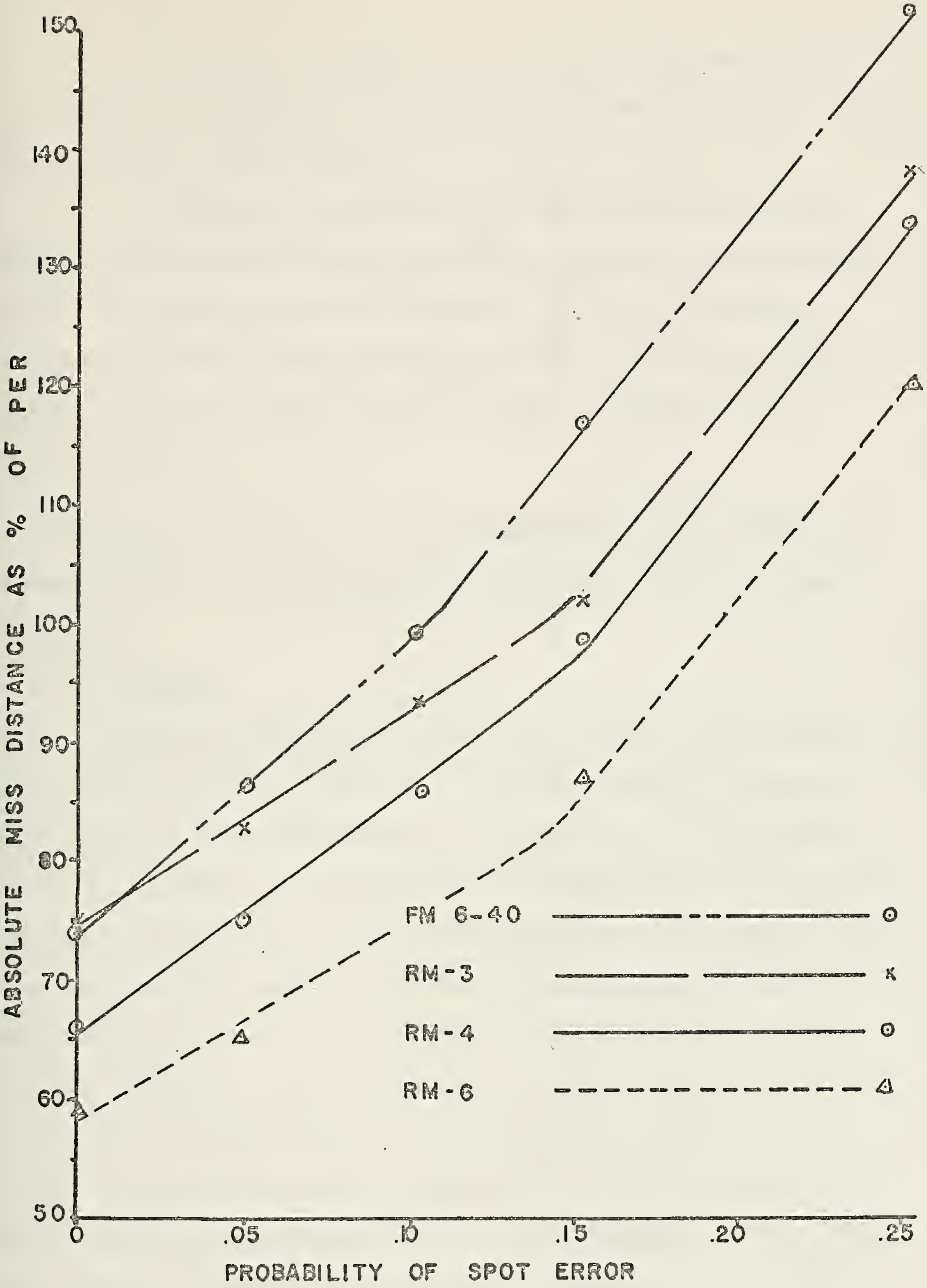


Figure 3 - Effects of Errors on all Fire for Effect Rounds

e. Effects of Errors if Such Errors Occur Over the Entire Fire Mission to Include Both the Adjustment and the Fire for Effect Phases

Figure 4 indicates that all four procedures deteriorated rapidly when spot error probabilities exceeded 7.5%. As in previous error models, all three proposed procedures showed significantly better abilities in estimating the true target center at the completion of the registration.

D. COMPARISON OF FM 6-40 AND RECOMMENDED ROBBINS-MONRO ONE ROUND PRECISION FIRE PROCEDURES THROUGH COMPUTER SYSTEMS SIMULATION

1. General

The preceding quoted results, based on the simplified model, clearly indicated that the proposed Robbins-Monro type 1 round technique was superior to the current FM 6-40 procedure in estimating the registration corrections needed to place the mean of the ballistic distribution onto the true target center. However, these results could be misleading due to the simplistic assumptions made. For example, precise range corrections to the nearest fraction of a meter are for all practical purposes impossible to attain due to fire control instrument setting limitations. Elevation can be set accurately to the nearest 0.1 mil when the gunner's quadrant is employed. Depending on the terminal trajectory, 0.1 mils could correspond to several meters. Additionally, the effects on the accuracy as a

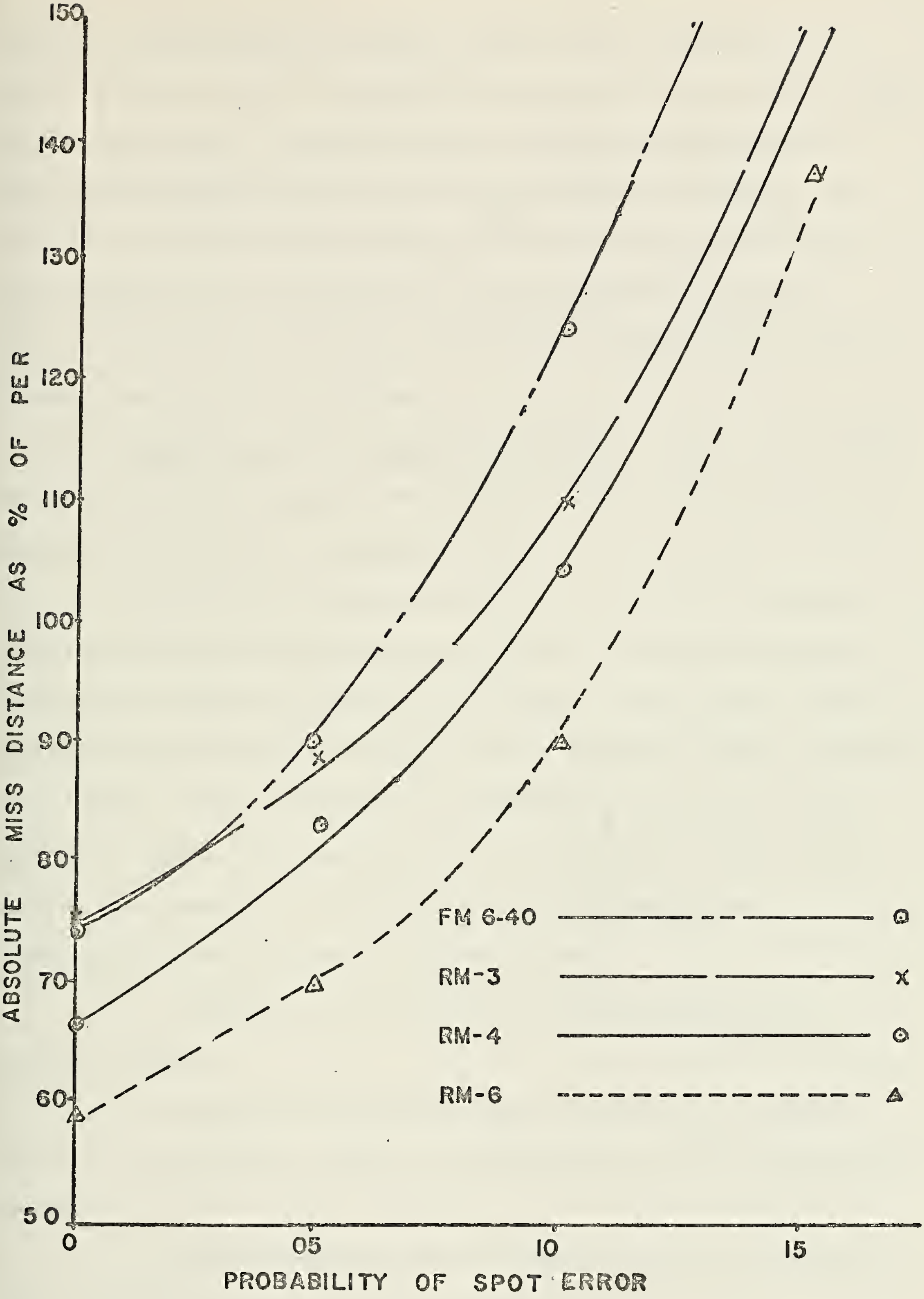


Figure 4 - Effects of Errors on all Fired Rounds

result of employing an angle T other than zero mils, as well as the effects of applying deflection corrections, must be investigated. To account for systems and procedural limitations which may exist in the conduct of actual precision fire, and to provide a more realistic insight into the comparative accuracies of the current and proposed precision fire procedures, a computer system's simulation program was written and used.

2. Brief Computer Program Description (For the listing of the computer programs employed in this section, the reader is referred to Appendix F.)

The program package consists of the main program and 19 functional subprogram routines. The main program controls the imput parameters, (range, target size, target orientation, angle T, angle T error, observer errors, observer target range, ammunition parameters, etc.), the main decision steps and computation of statistics of miss distances and ammunition expenditures. The functional subprograms perform the following tasks:

a. Generate uniform U(0,1) and normal N(0,1) random numbers.

b. Perform coordinate transformations of impact points from the gun target to the observer target coordinate system.

c. Determine the initial range shifts to be used by the observer at the start of each mission.

d. Round off all observer sensings and adjustment

phase fire direction center range corrections to the nearest ten meters.

e. Determine if the observer spots the bursts as OVER, SHORT, DOUBTFUL, LEFT, or RIGHT of the target.

f. Transform observer burst spottings into fire direction center spottings of range and deflection.

g. Determine observer range errors used to simulate observer estimation of range of impact prior to selection of initial shifts to use at start of each mission.

h. Determine observer deflection errors to simulate estimation of burst deviation if observer is equipped with field glasses.

i. Determine the C-factor (the number of mils needed to move the mean of the ballistic distribution 100 meters in range) to be used to establish the actual correction in meters when elevation settings to nearest mil or 0.1 mils are applied to howitzer.

j. Determine if the adjusted deflection has been achieved.

k. Determine the actual fire for effect FORK.

l. Determine the FORK rounded to nearest even mil value as employed by the current procedure.

m. Determine the appropriate rounding off of all deviation corrections to nearest 1mil in deflection to simulate howitzer deflection setting limitations.

n. Determine the appropriate rounding off of all corrections to nearest 0.1 mils in elevation to simulate howitzer elevation setting limitations.

3. The Ammunition Data Base

For the purpose of this simulation, the ballistic input data was obtained directly from Firing Tables FT 155-AH-2 w/C/2 (Ref. 15) and is applicable to the 155 mm howitzer, the U.S. Army's primary direct support artillery weapon. The ranges, powder type and charge, and associated PERs and PEDs used for comparative purposes are as follows:

CHARGE/POWDER TYPE	RANGE IN METERS	PER	PED
5/ green bag	2000	7	1
5/ green bag	6000	13	3
5/ white bag	5500	20	3
6/ white bag	8000	27	4
6/ white bag	10000	34	5

The choice of these particular ammunition parameters was motivated by a desire to attain a representative range of PER values available within the firing tables (Ref. 15). The data associated with PER values of 13, 20, 27 and 34 correspond to quadrant elevations ranging from 260 to 460 mils and consequently can be regarded as being representative for firing precision registrations at the indicated ranges. The quadrant elevation associated with PER=7 (elevation=80 mils) would rarely be selected for firing a precision registration due primarily to the resultant "flat" trajectory achieved which tends to limit the practical applicability of registration correction data for engaging other targets directly. However, selection of PER=7 set

proved to be fortuitous in showing some adverse effects upon the accuracy of the FM 6-40 registration procedure which will be discussed.

4. Assumptions

a. Target Size and Target Hits

At the recommendation of the Review and Analysis Branch, the Gunnery Department, Fort Sill, Oklahoma (Ref. 18) a 10 by 10 meter target is employed. Any computer generated impact within the target area is considered to be target hit.

b. Observer Target Range

The range from the observer to the target was set at 2500 meters for all registration missions simulated. 2500 meter observer target range is considered by this author to be average encountered in actuality.

c. Probable Error in Range

The PER is assumed to remain constant throughout the mission rather than as a function of the actual gun target range. This assumption was made for program simplicity, and should be considered reasonable. Over the firing table ranges employed, the input PER remained within ± 1 meter of the tabulated "true" PERs. For deflection, the program input PED corresponds to the tabulated PED.

d. Functional Representation of the C-factor

For program simplicity, the C-factor is assumed to be linearly dependent on range. The resultant error in treating C-factor linearly within ± 500 meters of true target range rarely exceeded 1 meter and in most instances was much less.

e. Initial Impact Location

It is assumed that the initial round for all missions will strike within an 800 by 400 meter rectangle centered on the true target location with the major axis of the rectangle parallel to the gun target line. Within the rectangle, the impacts generated are uniformly distributed in range ± 400 meters and deflection ± 200 meters.

f. Observer Spottings of Initial Round Impact in Range

For the purposes of this simulation program, it is assumed that the observer's ability in estimating the miss distance in range of any round is directly proportional to the actual miss distance of the round. The observer estimate of range miss distance used is: ESTIMATED MISS DISTANCE= ACTUAL MISS DISTANCE ± P(ACTUAL MISS DISTANCE) where P is uniformly distributed U(0,1). P can also be loosely interpreted as a percent error of actual range miss distance the observer will make, and on the average the error made by the observer will be 50%. For example if the actual burst miss distance in range were 200 meters, the observer is just as likely to estimate the miss distance to be 100 meters as 300 meters. This range estimate is used only on the initial round to simulate observer choice of the initial range bracket for the adjustment phase. For example, if the observer estimates the initial range miss distance to be 150 meters, the initial adjustment bracket chosen would be 200 meters.

g. Observer Spotting of Burst Deviations in Adjustment Phase

The observer is capable of spotting burst deviations within 5 mils with field glasses (Ref. 18). With an observer target range of 2500 meters this implies that the observer can spot the impact deviations within 12.5 meters.

h. Observer Spotting of Impacts Striking Over, Short, Left and Right of the Target

It is assumed that the forward observer will make errors in spotting primary quadrant location of impacts with some probability, with the probability of range error being greater than deviation error. The reader is referred to Appendix A for full discussion of observer spot capability model used.

i. No computational errors will be made by the fire direction center.

j. No excessive gun crew errors in setting the appropriate quadrant elevation and deflection will be made. Those errors which occur in leveling of fire control instrument bubbles and errors in deflection sight alignments will be discussed with results.

k. Angle T Error

The angle T error is assumed to be normally distributed N(0,66₥). A standard deviation of 66 mils in establishing the direction from the observer to the target may be too excessive, but as will be discussed in the results section, such an error had insignificant effects on achieved accuracies.

5. The Results

The results to be discussed are based on 750 replications of the system's simulation comparison of the FM 6-40 and the proposed Robbins-Monro type 1 round precision registration procedure. Because of the complexity and length of the computer program, 750 replications was selected to insure that computer CPU time remained less than four minutes. Selective runs with 2000 replications produced no significant change from results attained at 750 replications. For the purposes of this comparison, GUNS ON THE LEFT case is treated. This implies that the angle T is the acute clockwise angle as measured from the observer-target to the gun target lines, and indicates which set of tables to use for conversion of forward observer primary quadrant burst spots to fire direction center spots. Although the programs as written are capable of investigating the full range (0 to 3200 mils) of angle T values for the guns on the left situation, only the 10, 200, 400, 600, 800, and 1600 mil generated data will be presented and discusses. Although both procedures use identical parameter inputs, the generated results are biased in favor of the current FM 6-40 registration procedure in the sense that all 5 and 1 range spot registrations are eliminated from consideration in the statistical analysis of final results. Elimination of 5 and 1 fire direction range spot registrations produces two effects. First, the data for the average number of rounds needed to complete a registration will be

less than if additional rounds were considered for verification purposes. Secondly, using only 4 and 2, or 3 and 3 range spot combinations provides a much greater assurance that the mean of the $\frac{1}{2}$ FORK bracket at which the "preponderance" formula is applied is well within the 2 PER stable range; in fact, from the generated results it appears that the mean of the $\frac{1}{2}$ FORK bracket is around 1.5 PER from the true target center where maximum accuracy occurs. For the proposed procedure, all missions were considered to be valid and none were eliminated from consideration.

a. Discussion of Results

The tabulated results from the comparative computer simulation of the two procedures are presented in Appendix C. Only pertinent general findings will be presented here. In the discussion, the "no error" model refers to Observer Capability Model 1 and the "error" model refers to Observer Capability Model 2 as presented in Appendix A. The current registration procedure is abbreviated as FM 6-40. The Robbins-Monro type registration technique is abbreviated RM; the number associated with RM refers to the number of fire direction center positive range spot rounds, (to include the last initial bracketing round) used in calculating the registration adjusted elevation.

(1) The "No Error" Model Results

The results for the range component of the miss distance will be presented in terms of average absolute miss distance as a function of actual PER used. The pooled

average absolute range miss distance over all angle Ts for the computer simulation will be compared to those predicted by the asymptotic convergence theory discussed in Sect. III.

(a) Results for PERs 20, 27, and 34 meters

PROCEDURE	PREDICTED	SIMULATION RESULTS PER=20	PER=27	PER=34
FM 6-40	.732PER	.704PER	.697PER	.697PER
RM3	.717PER	.732PER	.725PER	.715PER
RM4	.664PER	.675PER	.684PER	.664PER
RM5	.623PER	.622PER	.629PER	.617PER
RM6*	.586PER	.586PER	.595PER	.586PER

*note: the six round version is equivalent to like number of FM 6-40 rounds.

The close agreement with theoretically predicted results is somewhat surprising when one considers that systems limitations, target hits, and various round off rules were employed within the computer program. The better than predicted showing of the FM 6-40 procedure (5%) should not be viewed with alarm, for all 5 and 1 range spot combination registrations were eliminated from consideration. This elimination apparently has the effect of locating the mean of the $\frac{1}{2}$FORK bracket at which the "preponderance" formula is applied in a range of 1 to 1.5 PER from the true target center where maximum accuracy is achieved. As was discussed in Section III, an 8% improvement in accuracy (as compared to asymptotic theory results) can be expected when the mean of the $\frac{1}{2}$FORK bracket is 1.5 PER from the true target center.

(b) Results for PER = 13 Meters

PROCEDURE	PREDICTED	SIMULATION RESULTS
FM 6-40	.732PER	.704PER
RM3	.784PER	.779PER
RM4	.717PER	.701PER
RM5	.664PER	.647PER
RM6	.623PER	.602PER

The difference in the predicted values for the Robbins-Monro 1 round proposed procedure, when compared to (a) above, stems from the use of 1 less round from the fire for effect phase when PER is less than 18 meters.

(c) Results for PER = 7 Meters

PROCEDURE	PREDICTED	SIMULATION RESULTS
FM 6-40	.806PER	.788PER
RM3	.814PER	.809PER
RM4	.728PER	.703PER
RM5	.665PER	.642PER
RM6	.615PER	.587PER

As was mentioned earlier in the discussion, the results for PER=7 meters showed marked differences from the other PER values. This apparent contradiction may be explained when a comparison is made with the extracted tabulated data from Reference 15. Table G of that reference indicates that PER=7 meters for the gun target range of 2000 meters, but Table F of the same reference gives the value of FORK as

1 mil and the C-factor as 4.5 mils. This implies that the recursive constant FORK is 22.2 meters rather than 4 PER which is equivalent to 28 meters. Additionally, since the FORK value in the tables is given as 1 mil and the current procedure employs FORK values to nearest even mil (in this case 2 mils would be used), the bias variance will be greater than PER^2; accounting for the differences, the bias introduced would be about $(11.1/7\ PER)^2$. Thus, in this specific instance using an even FORK value for the current procedure had a marked detremental effect on the accuracy of the adjusted registration data. Conversely, the proposed procedure was favored in the sense that the effective step constant was less than 2FORK.

(d) Accuracy of Adjusted Deflection

The adjusted deflection for both the current and the proposed procedure were generally within 1±0.5 mils with better adjusted deflection achieved by the recommended procedure. It is significant that the proposed procedure attained as good or better adjusted deflection; this lends support to the recommendation that deflection corrections should be applied after every positive fire direction center deflection spot, and that firing additional rounds to achieve "correct" deflection as prescribed by FM 6-40 results in needless expenditure of ammunition without improvement of adjusted deflection data.

(2) The "Error" Model Results

Examination of the tabulated data results found in Appendix C again support the contention that the

proposed procedure is superior in accuracy for determining adjusted registration data. No attempt will be made here at a comparison with any theoretically predicted results due to the extreme difficulty which would be encountered in formulating a closed form mathematical model to account for all probabalistic interactions which do occur; only general comments will be made.

(a) Effects of Angle T on Adjusted Range

Results from the "no error" model indicate that no appreciable Angle T effects on the adjusted range data occurred. With the "error" model, this appears to be no longer true, particularly when examining Angle T = 600 mils data; a very marked deterioration of the FM 6-40 procedure occurred when compared to the proposed procedure. This deterioration may be explained readily by considering the nature of the minimal spot error region which extends 20° on either side of the observer target line at the target (refer to Appendix A). The proposed procedure makes successive adjustments in the opposite direction of the range spot which means in essence that the ballistic mean is continuously adjusted toward the true target center. Also taking into consideration that simultaneous deviation corrections are being applied, the proposed procedure will cause rounds to impact more frequently into areas where the observer appears to have the best probability of making the correct spot. The current procedure, on the other hand, requires that fire for effect rounds be fired 1 FORK and

$\frac{1}{2}$ FORK apart with the result that on most occasions the deflection corrections are insufficient to move impacts into areas where the observer is least likely to make spot errors. Because of the "cookie cutter" type error probability separation, the results for 600 mils definitely appear to be biased in favor of the proposed precision fire procedure.

(b) Effects of Angle T on Adjusted Deflection

Due to the nature of the spot capability model where the probability of making an incorrect range spot is greater than for a deviation spot, the adjusted deflection error is greatest when Angle T is 1600 mils as it should be, for in this instance the observer range spots are fire direction center deflection spots. As in the "no error" model, the proposed procedure adjusted deflection was as accurate or better than for the current FM 6-40 procedure.

(3) Other Error Effects

(a) The Effects of Gun Crew Errors in Setting Elevation and Deflection Corrections

Gun crew errors are modeled under the assumption that the errors in applying quadrant elevation would be normally distributed $N(0,\sigma_{error})$. For both elevation and deflection setting errors, $\sigma_{error} = 2$ mils was investigated. Although such errors in deflection may be reasonable, they do seem to this author to be extreme for elevation settings, especially if a gunner's quadrant is being employed where even fractional mil errors will cause

the leveling bubble to migrate to either end of the leveling vial. The effects of such errors on both procedures appeared to be equal, with the overall effect being as if the projectile PER and PED were increased by the amount of the error. For example, let us assume that 1 mil in elevation corresponds to 5 meters in range, and that $\sigma_{error} = 2$ mils and the PER for that range is equal to 10 meters. Since the error process is in essence independent of the fall of shot, the effective PER as a result of the error process would be,

$$PER_{eff} = \sqrt{(10)^2 + (.6745(10))^2} = 12 \text{ meters}$$

Thus in effect the PER was increased by approx. 2 meters.

(b) The Effects of Angle T Errors

Angle T Errors are those errors committed by the observer in establishing the observer target direction. Errors with a normal N(0,66mil) distribution had minimal effects on the achieved accuracy of either procedure, with accuracy deterioration being less than 5%. The results indicate that both the current and the proposed procedures were robust to even large angle T errors.

E. TARGET DESTRUCTION COMMENTS

Only a limited number of computer simulation runs were made to simulate the number of rounds needed to achieve a target hit for the first time. In all instances, the proposed procedure was able to achieve a target hit with fewer rounds (10% on the average) than the current precision

fire procedure, lending support to the hypothesis that making successive adjustments after each round, rather than after each group of six rounds, increases the probability of achieving a hit. The probability of obtaining a hit is directly dependent on the location of the mean of the ballistic distribution in relation to the target and the associated variance of the fall of shot about that mean; the closer the ballistic mean is to the target, the greater the probability of acheiving a hit. However, even if the ballistic mean coincided with the actual target center an expected large number of rounds are still required to achieve a hit for the first time. For example, engaging a stationary target as small as the Russian t-54 tank (6.5 by 3.5 meters) at a range of 8000 meters with a corresponding PER = 27 meters and PED = 4 meters, would still require on the average 66 rounds to obtain a hit provided that the elevation and deflection corresponding to the ACTUAL TARGET CENTER has been used throughout the mission.

Although the proposed procedure on the average achieved a target hit with fewer rounds than the current procedure, the time to achieve that hit for both procedures is excessive. It appears to the author that time on the battlefield is frequently more critical than the cost of ammunition expenditure, and as such neither procedure firing a single round at a time is the appropriate means of attacking a static target. A better way of engaging such targets, when time to destruction is critical, would be to fire the entire

battery using the closed sheaf and make successive corrections in the manner described for the proposed fire procedure. Although more ammunition may be expended, the time to attain destruction should be lessened. To see how the recommended procedure may be used in this manner, let us look at a hypothetical example. Suppose a bridge needs to be destroyed to impede an enemy's movement. Suppose that the time to destroy that bridge is critical and that no means other than artillery fire is available for this task. A way to accomplish this is to use the base piece initially to achieve the first adjusted elevation (corresponding to the precision fire registration adjusted elevation). Let us assume that the fire for effect FORK = 12 mils and the adjusted elevation using the base piece comes out to be 320.6 mils and that n, the effective round number, is 9. Rather than continue firing with only the base piece, the entire battery in closed sheaf form is fired with the quadrant elevation of 320.6. The observer reports the primary quadrant location of the six round burst in relation to the target. Let us assume that as the result of firing the entire battery the fire direction range spot of the mean range burst is OVER. The correction for the next volley would be

$$- \text{FORK}/n = -12/10 = -1.2 \text{ mils}$$

and the volley would be fired at a quadrant elevation of 319.4 mils, and so on until the desired effects are achieved. No subsequent corrections to the sheaf should be necessary

or warranted once the initial corrections for the closed sheaf are calculated. One should be aware that EACH volley in closed sheaf form is being treated as if a SINGLE round were being fired. This procedure affords additional flexibility to the fire direction officer in the sense that he may decide at any point in the fire for effect phase to shift from the single gun to battery adjustment, a procedure he can not use with the current FM 6-40 precision fire technique. If time is not an important element, but ammunition is, then, as already mentioned, the proposed procedure will on the average achieve a target hit with fewer rounds than the current procedure.

V. PROPOSED PRECISION FIRE PROCEDURE FOR OBSERVER EQUIPPED WITH LASER RANGE FINDER

A. GENERAL

The introduction of the laser range finder into the artillery inventory provides the artillery observer with a capability he has not possessed previously - that of accurately estimating the precise burst location. How should this new observer capability be employed in precision fire to maximize the accuracy of registration correction data, and also maximize the probability of achieving a target destruction? A proposal currently being evaluated for precision registration, (Ref. 10), is to use the laser range finder to conduct a center of impact (CI) type of registration. A CI registration consists of firing several rounds (usually six) at single fixed howitzer quadrant elevation, with the observer lasing to each burst. Knowing the precise location of the observer, the fire direction center can compute the grid location of the mean point of impact of the rounds fired. The difference in the calculated mean point of impact and the "should hit" grid, give the registration corrections.

Although the CI procedure described is simple in concept, and dispenses with the requirement of having a surveyed target point, it does have several major drawbacks:

1. The observer must be precisely surveyed relative to the howitzer firing the registration, with directional

survey (the laser orienting azimuth) being the most critical element. For example, if the directional survey is in error by 5 mils, and the CI registration is at an observer impact range of 5000 meters, the registration corrections will be in error by 25 meters.

2. The laser range finder must be properly calibrated for range. If, for example, the calibration error in range is 10 meters, the error in the registration correction data will be 10 meters.

3. Target destruction type missions cannot be readily fired. Although after each group of rounds a correction for range and deflection can be computed, such computations tend to be cumbersome even with the field artillery automatic data processing equipment (FADAC and TACFIRE).

The method which is recommended for precision fire if the observer is equipped with the laser range finder is a special case of stochastic approximation techniques first discussed by Grubbs (Ref. 8). A surveyed registration point is required; but observer's location need not be surveyed. The procedure is similar to the one recommended if the observer is equipped with field glasses, in that an appropriate correction is made for each round fired. Rather than using a recursive constant such as FORK/n, a fraction of the actual miss distance of the impact in relation to the target is used. The correction to fire the second round corresponds to the actual miss distance of first round reported; to fire the third round, 1/2 of the second

round miss distance is applied; for the fourth round it is 1/3 the miss distance of the third round, and so on until the mission is terminated. Recursively, the formula for making corrections to estimate the target center location is,

$$X_{n+1} = X_n - \frac{1}{n} (Y_n)$$

where: X_{n+1} = the n+1st estimate of the target center, or the data at which the n+1st round should be fired (either the quadrant elevation or deflection),

X_n = The data at which the last round was fired,

Y_n = The actual miss distance of burst in relation to the target on the gun target line,

n = the last or the nth round fired.

The identical form of the correction formula is used to determine both elevation and deflection corrections for each round fired. For the remainder of this discussion, the laser range finder recommended procedure will be referred to as the X-BAR procedure.

Evans (Ref. 6) showed and Barr (Ref. 1) proved that the n+1st computed correction for the X-BAR procedure is the same as if all n rounds were fired at the data corresponding to the mean of the ballistic distribution of the first round. This implies that the registration correction is in essence the difference between the "mean point of impact" grid of the n rounds fired (as if all n rounds were fired at the first round quadrant elevation setting) and the registration

point surveyed grid. An alternate interpretation can be made also - that the last correction applied represents the true target center estimate based on the sample mean of all impacts as though all rounds were fired with data corresponding to the previous target center aim point estimate. This latter interpretation is of special significance if target destruction is desired since the probability of achieving a target hit is maximized if the ballistic distribution mean coincides with the true target center. Barr (Ref. 1), Evans (Ref. 6), and Grubbs (Ref. 8) presented the following significant property attributes of the X-BAR procedure:

1. The successive corrections minimize the variance of the estimate of the true target center location after each round is fired.

2. The aimpoints after n rounds tend to be normally distributed about the true target center $N(0, \frac{\sigma^2_{range}}{n})$ and $N(0, \frac{\sigma^2_{deflection}}{n})$ where σ^2_{range} is the range component variance and $\sigma^2_{deflection}$ is the deflection component variance of the fall of shot along the gun target line, directly related to PER and PED (recall from previous discussion that $.6745\ \sigma_{range} = PER$ and $.6745\ \sigma_{deflection} = PED$).

3. The procedure maximizes the conditional probability of achieving a hit on the n^{th} round.

4. It minimizes the expected number of rounds required to hit the target for the first time.

5. The last round fired contains the information of all the previous rounds fired. This fact is of particular

significance if the procedure is to be computerized since valuable computer core space is saved.

B. THE RECOMMENDED METHOD OF USING THE X-BAR PROCEDURE FOR ARTILLERY PRECISION FIRE

1. Basic Assumptions

a. The forward observer is equipped with the laser range finder and is capable of providing "accurate" (subject to some error) observer burst range and azimuth data to the fire direction center.

b. For a precision registration, a surveyed registration point exists.

2. The Procedure

a. Unlike the precision fire methods discussed in Sections II, III, and IV, only a fire for effect phase is employed.

b. Establishing the initial Base Range and Base Azimuth

The observer lases several times to the target and reports the mean range (to the nearest meter) and direction (to the nearest mil) to the fire direction center; this establishes a base range (BR) and a base direction (BA) for computing subsequent burst miss distances. Once the base range and direction are established, the observer lases only on impact bursts.

c. Laser Orienting Round

The base piece fires an initial round corresponding to the grid location of the registration point. The

purpose of this round is to provide general orientation for the laser range finder for lasing of all subsequent bursts.

d. Fire For Effect Phase

For each round fired, the observer reports to the fire direction center the lased range and direction to the burst. The fire direction center, using the base range and base direction to the target and the lased range and direction to the burst, computes the gun target impact range and deviation miss distance. As an example, let us assume that the observer is on the gun target line, and that the base range to the target is 3000 meters (note; the base range corresponds to the observer target range). Suppose that lased range and direction to burst reported to the fire direction center are 3150 meters and 40 mils. The gun target burst miss distance is:

BURST RANGE - BASE RANGE = 3150 - 3000
RANGE MISS DISTANCE = +150 meters
BURST DIRECTION - BASE DIRECTION = 40 - 0
DEVIATION MISS DISTANCE = 40 mils(3000/1000)
= 120 meters right

If the observer is not on the gun target line, the computations become somewhat more difficult since the computed miss distances must be translated from the observer target to the gun target lines. Two methods are recommended. If the FADAC or TACFIRE computers are available, they should be used since both are currently programmed to perform such translations. If computers are not available, then the M-10

plotting board is recommended. Once the gun target miss distance is computed, the quadrant elevation and deflection corrections to fire the next round are found by applying the correction formula

$$\text{CORRECTION} = 1/n(\text{MISS DISTANCE})$$

where n represents the n^{th} positively lased round. Since corrections in meters can't be applied directly to howitzer fire control instruments, they must be converted to the nearest .1 mils for range and nearest 1 mil for deflection; both the FADAC and TACFIRE programs make this computation. For the manual mode, the following procedure is recommended:

Using the firing table C-factor, the computed gun target range miss distance is converted to nearest .1 mils and then the correction formula applied. For example, after firing the third round, the gun target calculated miss distance is 45 meters. Assume that the C-factor is 10 mils. Using this C-factor, 45 meters converts to 4.5 mils. The quadrant elevation correction to be applied to fire the fourth round is

$$\begin{aligned}\text{QE CORRECTION} &= -1/3(4.5 \text{ mils})\\ &= -1.5 \text{ mils.}\end{aligned}$$

If the impact had been 45 meters short the correction would have been +1.5 mils. The deflection corrections are made in the same manner except that the mil-range relationship is used.

The final adjusted quadrant elevation and adjusted deflection of an "n" round registration corresponds

to the quadrant elevation and deflection used to fire the n^{th} round plus the corrections computed as if the $n+1^{st}$ round is to be fired. If the observer reports a target hit, the next round is fired at the same data at which the target hit was attained. Since a target hit is a positively lased round, the positively lased round number counter ("n") is advanced by 1. Occasions will arise when the observer fails to attain a burst lasing. In such instances, the round is refired without advancing "n", the counter for positively lased rounds.

C. COMPUTER SYSTEM'S SIMULATION OF THE X-BAR PROCEDURE

1. General

The theoretical treatment of the X-BAR procedure in quoted references was conducted under the assumption that precise corrections to miss distances could be applied. Since system limitations do exist which limit the precision of correction settings, a computer simulation program of the X-BAR procedure incorporating setting limitations, computational round-offs and various crew errors was written and employed. Answers to two primary questions were sought: first, "What accuracies in registration data can one expect from the X-BAR procedure?", and secondly "How does that accuracy compare with the current FM 6-40 and the Robbins-Monro 1 round procedure discussed in Section IV?".

2. Brief Computer Program Description

For the listing of the program, the reader is referred to Appendix G. The program package consists of the

main program and twelve functional program routines. The main program controls the input parameters, the main decision steps, and the computation of statistics of miss distances and ammunition expenditures. The functional programs do the following:

a. Generate uniform U(0,1) and normal N(0,1) random numbers.

b. Perform coordinate transformations of impact points from the gun target to the observer target coordinate systems.

c. Round off observer range measurements to the nearest meter and direction measurements to the nearest mil.

d. Determine the appropriate C-factor to use.

f. Determine the appropriate rounding off of all corrections to nearest mil in deflection and nearest 0.1 mils in elevation to simulate howitzer elevation setting limitations.

g. Determine and apply gun crew errors in setting quadrant elevation and deflection.

3. The Ammunition Data Base

The ballistic input data is the same as for the simulation programs of Section IV.

4. Assumptions

a. The assumptions regarding target size and target hits, the constancy of PER and PED, the linearity of the C-factor function, initial impact location, fire direction center errors, gun crew errors, and the angle T errors are

the same as those for the simulations of the Robbins-Monro and the current FM 6-40 procedures.

b. It is assumed the observer will positively lase every round. No attempt was made to simulate missed rounds. Under the assumption of round to round independence if fired with the same setting, the only effect of not lasing a round should be to increase the total number of rounds fired for any one mission.

c. The assumption is made that the slant range from the range finder to the burst is the same as if both the instrument and the impact point were at the same altitude. Although this assumption may be critical for CI type registration, this altitude differential is of minimal significance in the performance of the X-BAR procedure. To see this, let us assume that the observer target range is 1000 meters, and the altitude of the laser is 1000 meters above the impact point; let us further assume that a burst occurs 50 meters beyond the target, giving a true horizontal laser to target range of 1050 meters. Using the CI procedure without adjusting for slant would produce a range error of 420 meters. Using the X-BAR method under the same assumptions produces only a 4 meter error. Since 45° slant angles would rarely be encountered the assumption made regarding insignificance of slant ranges should be considered valid.

5. The Results

The results to be discussed are based on 750 replications of the X-BAR procedure. 750 was chosen to coincide

with the number of simulation trials used to analyze the FM 6-40 and the Robbins-Monro 1 round procedures (Section IV) to provide a reasonable direct comparison of the relative accuracies of the competing procedures using identical ballistic and angle T parameter inputs. The X-BAR computer simulation results are tabulated in Appendix D. Only some pertinent general findings will be presented in this discussion.

The results will be presented in two forms. For the "no error" case (to be discussed) the accuracy of the adjusted range component of the registration will be presented in terms of the absolute miss distance as a function of PER. This will provide a standard measure for any PER value which may be used. The "error model" (to be discussed) will be presented in "normal form", that is, in terms of the standard deviation of the distribution of the final adjusted registration aimpoints. The adjusted aimpoints correspond to the estimate of the true target center location at the completion of the registration. Using the "normal form" will provide an easier means for comparison of the generated results with those theoretically predicted when laser error processes are involved. The tabulated results in Appendix D are presented both in the "normal form" and in terms of mean absolute miss distances expressed in meters. In the discussion, reference to the number of rounds for the X-BAR procedure will be made; the numbers correspond to positively lased rounds used in the computation of registration

adjusted data and do not include the initial laser orienting round or any missed (non-lased) rounds.

a. The No-Error Results

It is assumed that the observer is capable of accurately lasing actual burst location to the nearest meter in range and the nearest mil in direction.

(1) The Accuracy of Adjusted Range

The predicted results will be based on the theoretically quoted distribution of the aimpoints. For range, the predicted mean absolute miss distance of an "n" round X-BAR registration is

$$\text{ABSOLUTE RANGE MISS} = \sqrt{\frac{2}{\pi n}\left(\frac{\text{PER}}{.6745}\right)^2}$$

The simulation results are derived by pooling the mean absolute range miss distances for all the angle T values investigated. The comparison between predicted and attained results are as follows:

PER	# OF ROUNDS	PREDICTED RESULTS	SIMULATION RESULTS
7	4	.591PER	.570PER
	6	.483PER	.475PER
13	4	.591PER	.607PER
	6	.483PER	.499PER
20	4	.591PER	.586PER
	6	.483PER	.489PER
27	4	.591PER	.597PER
	6	.483PER	.483PER
34	4	.591PER	.579PER
	6	.483PER	.481PER

The close agreement with theoretically predicted results is significant from the standpoint that the simulation accounts for systems limitations in howitzer elevation and deflection settings and the rounding off of lased ranges to nearest meter and azimuths of the bursts to nearest mil. A comparison with the "no error" models of Section IV shows that the X-BAR 4 round registration data for all PERs is as accurate as the proposed Robbins-Monro 6 round base registration and more accurate than the current FM 6-40 procedure. This is significant from the ammunition expenditure viewpoint; on the average, the FM 6-40 and the Robbins-Monro 1 round registration procedures expended 12 rounds in the adjustment and fire for effect phases to achieve the registration correction data.

(2) The Accuracy of Adjusted Deflection

In all instances the gun-target range mean absolute deviation error of the adjusted deflection was less than 0.5 mils.

b. The Laser Range Finder Error Results

The assumption is being made that errors will be committed in lasing range and direction of the burst. It is further assumed that the range and direction errors are uniformly distributed U(-error,+error) (Ref. 18). Three error combinations were treated:

Range Errors	Azimuth Errors
± 10 meters	± 2 mils
± 20 meters	± 4 mils
± 40 meters	± 8 mils

Only the ±20 meter range and the ±4 mil azimuth errors at angle T = 10 mils will be discussed in terms of theoretically predicted results; for the complete tabulated results the reader is referred to Appendix D.

The effect of the laser error is to increase the apparent PER and PED by an amount proportional to the standard deviation of the lased error. The apparent standard deviation (σ_{app}) in range instead of being PER/.6745 is now,

$$\sigma_{app} = \sqrt{\left(\frac{PER}{.6745}\right)^2 + \frac{(40)^2}{12}}$$

and the effective probable error in range, $Per_{eff} = .6745\sigma_{app}$. From this it follows that the estimates of the true target center after an n-round X-BAR registration should be normally distributed $N(0, \frac{\sigma_{app}}{n})$ in range. The same logic may be applied to attain the aim point distribution of the deviation component. At this point it should be noted that the above development of the apparent range standard deviation was derived under the assumption that the observer was located on the gun-target line. For Angle Ts greater than zero mils the σ_{app} computations tend to be somewhat more complicated and one must resort to trigonometric methods to compute the gun-target effective error distribution.

(1) The Accuracy of Adjusted Range

As with the "no error" model, the simulation results closely parallel those theoretically predicted. The results presented in normal form are as follows:

PER	NUMBER OF ROUNDS	PREDICTED σ	SIMULATION σ
7	4	7.76	7.71
	6	6.07	6.03
13	4	11.23	11.49
	6	9.17	9.39
20	4	15.91	16.13
	6	12.99	12.91
27	4	20.83	20.78
	6	17.00	17.11
34	4	25.86	26.16
	6	21.11	21.22

note: to obtain the mean absolute miss distance in range, the reader should multiply σ by 0.8.

(2) The Accuracy Of Adjusted Deflection

As the laser range finder error distribution parameters increased, the accuracy of the adjusted deflection deteriorated. With the maximum error distribution, (range error = ±40 meters and azimuth error = ±8 mils) the mean absolute adjusted deflection was within 1.5 mils of true deflection for all but PER=7 meter data. For the 4 round X-BAR registration (PER=7) simulated at Angle T = 1600 mils the mean absolute adjusted deflection was 4.3 mils (8.6 meters) in error. This should not be surprising in view of the large laser range finder error being introduced. At Angle T = 1600 mils, the effective PED instead of being 1 meter is 15.6 meters.

(3) A Comparison of X-BAR, FM 6-40 and the Proposed Robbins-Monro 1 Round Registration Procedures

A comparison of the relative accuracies of the "no error" FM 6-40, the proposed Robbins-Monro 6 round equivalent and the "error" model X-BAR 6 round registration is presented. The measure of accuracy used is the radial error in meters of the estimate of the true target center at the completion of the registration. The data was extracted from Appendix C and Appendix D. The error model associated with the X-BAR procedure assumes the distribution of laser ranging as being U(±20 meters) in range and U(±4 mils) in azimuth. The error corresponds to the upper bound of lasing errors as recommended by the Review and Analysis Branch of the Gunnery Department, Fort Sill, Oklahoma (Ref. 18).

ANGLE T	PROCEDURE	PER=7	PER=13	PER=20	PER=27	PER=34
10₥	FM6-40	6.30	10.84	15.67	20.20	23.61
	R-M	4.56	8.78	12.45	17.70	21.89
	X-BAR	5.07	8.22	10.79	14.32	18.58
200₥	FM 6-40	6.15	10.67	15.37	21.13	26.24
	R-M	4.68	9.23	12.37	17.64	20.58
	X-BAR	4.98	7.61	10.71	13.65	17.88
400₥	FM 6-40	6.13	10.20	15.61	21.60	26.09
	R-M	4.45	9.04	12.88	17.37	22.77
	X-BAR	5.07	7.94	10.81	14.45	18.28
600₥	FM 6-40	6.37	11.43	16.84	26.23	34.96
	R-M	4.61	8.87	13.61	17.58	22.31
	X-BAR	5.37	7.88	10.23	14.17	17.46
800₥	FM 6-40	5.81	11.09	16.87	23.14	29.74
	R-M	4.53	9.40	13.53	18.56	23.64
	X-BAR	5.35	8.35	10.44	13.98	17.16
1600₥	FM 6-40	6.33	10.33	15.08	20.36	25.15
	R-M	4.37	8.99	12.35	17.91	21.69
	X-BAR	5.40	8.15	10.94	14.10	17.73

The preceding tabulated results clearly indicate the superiority of the X-BAR procedure in achieving greater registration accuracies with approximately one half the ammunition expenditure needed by both the current FM 6-40 and the proposed Robbins-Monro 1 round successive adjustment registration techniques.

c. Other Error Effects

(1) The Effects of Gun Crew Errors in Setting Elevation and Deflection Corrections

As is Section IV, gun crew errors were modeled under the assumption that the error in applying elevation and deflection settings would be normally distributed N(0,2mils). The effect of such errors is to increase the apparent PER and PED; this was discussed in Section IV. Such errors had an insignificant effect on the achieved accuracy.

(2) Effect of Angle T Errors

The Angle T error was modeled under the assumption that the error in establishing the direction to the target would be normally distributed N(0,66mils). Although such errors appear to be excessive, they may be encountered if the observer location is not surveyed and the observer had to resort to the M-2 compass to establish the initial direction to the registration point. As shown in the tabulated results which follow, such an error had insignificant effect on the accuracy of the registration. The X-BAR 6 round angle T error and the no error model for

PER = 27 meter data will be compared at Angle T = 10, 800 and 1600 mils.

ANGLE T	ANGLE T ERROR	MEAN ABSOLUTE RANGE ERROR IN METERS	MEAN ABSOLUTE DEVIATION ERROR IN METERS
10m̸	0m̸	12.88	3.37
	66m̸	13.59	4.46
800m̸	0m̸	13.43	3.37
	66m̸	13.78	4.54
1600m̸	0m̸	12.73	3.37
	66m̸	13.42	4.62

The insensitivity of the X-BAR procedure to large Angle T errors should not be surprising since all corrections are made with the registration point as the reference rather than the observer's position. Such an error on the CI registration currently proposed for observers equipped with the laser range finder fired at an observer-impact range of 2500 meters would result in a mean absolute error of 130 meters in the registration correction data.

(3) Effects of Laser Range Calibration Errors

It is assumed that the laser range errors in measuring the true observer to burst range could occur if the laser range finder is not properly calibrated; it is further assumed that such an error would remain constant for the entire precision fire mission to include establishing the base range. Because all corrections are made with the registration point as the reference, no error in the registration data will be made. As previously cited, for a CI registration, the corrections would be off by amount of the calibration error.

(4) The Effects of Errors in Establishing the Observer Location

The reference is made to those errors which result from errors in survey or errors of observer estimate of his true location from a map spot inspection. The X-BAR procedure is insensitive to such errors due to previously cited reasons; all corrections are made with reference to the target center location and not with respect to the observer location.

(5) The Effects of Errors in Establishing the Initial Base Range

Due to various factors, it may be reasonable to assume that a small error may be made when lasing to the target to establish the base range used by the fire direction center to compute subsequent firing corrections. The registration corrections in this instance will be in error by the amount of the base range error. To minimize this bias, the author recommended in paragraph B,2,b, of this section that several lasings to the target be made and the mean reading be used to establish the base range.

D. TARGET DESTRUCTION COMMENTS

Under the conditions assumed for conducting precision fire firing one round at a time, there is no other statistical sampling procedure which will provide greater probability of achieving a target hit than the X-BAR procedure. The following important theoretical results are requoted:

1. The procedure minimizes the expected number of rounds required to hit the target for the first time.

2. The procedure maximizes the conditional probability of achieving a hit on the n^{th} round fired.

However, as was noted in Section IV, making successive corrections after firing each round may not be the appropriate method to attack a static target if time to destroy that target is more critical than the number of rounds expended. In such an instance it may be more advantageous to fire the entire battery in closed sheaf form; the exact method to use to make successive corrections after each volley is fired should be investigated. One procedure this author recommends is to use the X-BAR registration procedure firing the base howitzer 1 round at a time for a specified number of rounds (say 4) and then switch to the Robbins-Monro volley adjustment technique described in Section IV using an appropriate recursive constant. For example, the probability that on the average the adjusted aimpoint will be within 1 PER in range of the true target center after a 4 round X-BAR procedure is 84%, which suggests that the recursive constant $\frac{1}{2}$FORK or less may be used.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. If the assumption is accepted that in precision fire primary quadrant spots in relation to actual target location is the best information about bursts that can be expected from an observer, then this study clearly shows (both analytically and through computer simulation) that the proposed Robbins-Monro adjustment technique is superior to the FM 6-40 precision fire procedure in the following respects:

a. The procedure should have greater intuitive appeal in that successive adjustments are made toward the target after each round is fired.

b. The successive correction algorithm is easy to remember and the decision rules for specific situations are less complicated than for the current FM 6-40 registration procedure. This will make training of fire direction personnel easier.

c. Information from the rounds fired in the adjustment phase can be used for all fire for effect PERs greater than 9 meters.

d. Information from graze bursts of time registration phase can be used to refine adjusted elevation data to provide greater accuracy of the estimate of the true registration point location.

e. The procedure was shown to be less sensitive to observer spot errors.

f. The fire direction officer is not bound to fire a specific number of fire direction center positively spotted rounds; the number of rounds to fire to attain registration corrections is now dependent on the desired accuracy of registration data.

g. In most instances, firing three fewer rounds than for the current registration procedure produced equivalent accuracy results.

h. In a target destruction mission, the proposed procedure will on the average achieve a target hit with fewer rounds expended.

i. The procedure can be adapted to fire a closed sheaf destruction mission if time to destroy the target outweighs ammunition expenditure.

2. If the forward observer is equipped with the laser range finder and a surveyed registration point exists, then the X-BAR registration is recommended over all other procedures to include the currently proposed laser range finder center of impact (CI) (undergoing field evaluation) procedure for the following reasons:

a. The successive corrections minimize the variance of the estimate of the true target center location after each round is fired.

b. It maximizes the conditional probability of achieving a hit on the n^{th} round.

c. The procedure was found to be generally insensitive to the following errors:

(1) Angle T errors

(2) Slant range errors

(3) Laser calibration errors

(4) Observer location errors

(5) Minor gun crew errors

(6) "Reasonable" observer lasing errors, provided such errors were within ±40 meters in range and ±8 mils in azimuth.

The author does see situations where the CI registration would be used. Situations will arise where surveyed registration points are non-existent; in such instances the CI registration either by flash base, radar or laser range finder methods must be resorted to.

3. At this point a "myth" regarding the FM 6-40 procedure should be dispelled. A figure quoted by the Gunnery Department, Fort Sill, Oklahoma (Ref. 17 and Ref. 19) is that the current registration procedure provides a 90% assurance that on the average the registration correction data will be within 1 PER of the true registration point. This figure is certainly true for the "no error" 6 round Center of Impact and the 6 round X-BAR procedure, but not for the FM 6-40 registration. The appropriate figure is 72%. The percentage was derived by using the theoretically developed standard deviation of adjusted range at the completion of a registration and applying the "Z-statistic"

$$P(-PER < TC-EC < PER) = \Phi\left(\frac{PER}{.732PER/.8}\right) - \Phi\left(\frac{-PER}{.732PER/.8}\right)$$

= 72%, where TC refers to true target center and EC is the registration estimate of true target center. For the proposed Robbins-Monro procedure this "probability" is 75% if no rounds are considered from the adjustment phase, and 83% for all registrations with fire for effect PERs greater than 18 meters.

B. RECOMMENDATIONS

The following recommendations are made:

1. That the field artillery adopt the proposed Robbins-Monro and the X-BAR precision fire procedures as the "standard" field artillery precision fire techniques, with the Robbins-Monro technique used only in instances when the observer is not equipped with the laser range finder.

2. That pertinent portions of Chapter 3 of Field Manual FM 6-40 (Ref. 14) be amended to reflect the theoretical accuracies developed in this study.

3. That the field artillery consider adopting the "closed sheaf" volley fire destruction technique.

4. That experiments in observer spot capabilities be conducted to investigate two distinct observer error processes:

a. The error probabilities of spotting the primary quadrant location of burst; that is, the spottings of OVERs, SHORTs, LEFTs and RIGHTs. If it is discovered that the probability of making a spot error is less than 5% then the

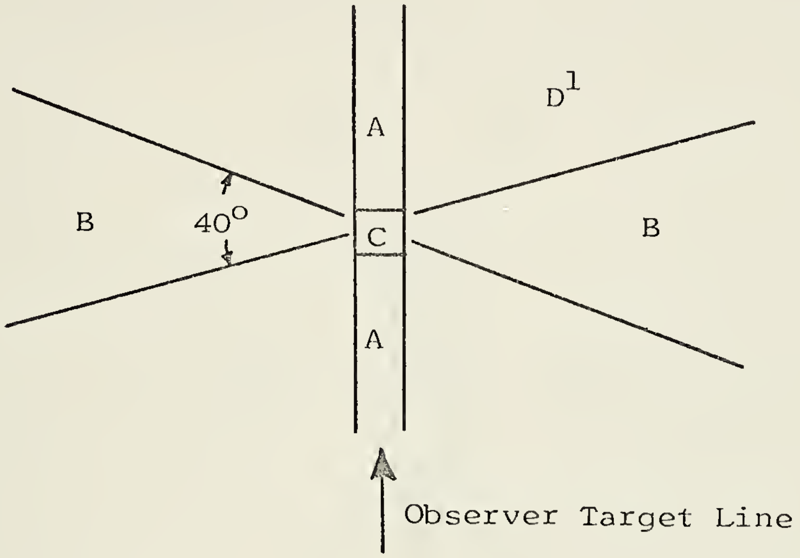
recursive constant for the Robbins-Monro technique could be reduced to $\frac{1}{2}$ FORK to achieve even greater accuracies.

b. The observer abilities to estimate distances of bursts which are in close proximity of targets (0-200 meters) at various observer target ranges. If as a result of this experiment it is found that the observer errors in estimating miss distances is on the order of modeled assumptions made in paragraph D,4 of Section IV, then the X-BAR procedure using observer field glass estimates of miss distances to compute registration corrections should provide greater accuracies of adjusted registration data than the proposed Robbins-Monro technique for the same cost in ammunition expenditure. This is based on the author's computer simulation results using the referenced observer error function. The data is not presented in this thesis because no assurance exists that the assumed error function may be reasonable.

APPENDIX A: FORWARD OBSERVER SPOT CAPABILITY MODELS

For the purposes of simulation comparisons of the current FM 6-40 procedure and the Robbins-Monro type 1 round procedure, two observer spot capability models are employed.

1. Spot Capability Model 1. The no error model.



NO ERROR MODEL

The following assumptions regarding the no error model are made:

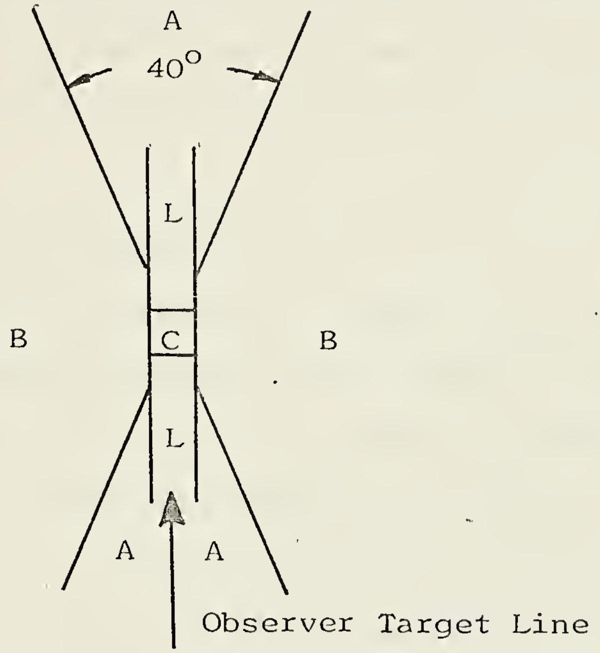
a. A generated impact falling within the 10 by 10 rectangle (C) is reported as a target hit.

b. An impact occurring in region B is reported as a doubtful spot - in other words, the observer is unable to differentiate if burst occurred short or over. The doubtful region is approximated by a cone whose central angle is 40° in manner shown in figure above.

c. A round landing within region A is reported as a line shot. Again the forward observer is unable to ascertain if the actual impact was to the left or right of the actual target center.

d. A burst occurring in all other regions is reported correctly. For example, if a round impacts in region D^1, the forward observer always spots it as OVER-RIGHT.

2. Spot Capability Model 2. The "Error" Model.



THE ERROR MODEL

The following assumptions regarding the error model are made:

a. A burst in region C will be reported as a target hit.

b. An impact in region L will be called a line shot.

c. The observer will on the average make a 2% error in spotting the deviation of a burst, regardless of burst location in relation to the target.

d. Range Spot Errors

(1) Region A - the maximum accuracy region. Any impact within region A will be spotted erroneously 2% of the time. In other words, 2% of the time an OVER will be sensed as impacting SHORT.

(2) Region B - the maximum error region.

(a) Of all rounds impacting within region B, 33% will be spotted as doubtful range.

(b) Of the rounds not spotted as doubtful range an incorrect spot probability will occur. Error probabilities of 5% and 25% for OVER and SHORT bursts were investigated.

e. Discussion of Assumptions for Model 2

(1) The most controversial aspect of the model is probably the shape and the extent of the maximum accuracy region. No one seems to know or has documented attempts to ascertain this facet of observer capability. The only reference available dealt with investigating the accuracy of mortar observers in directing high angle spotting rounds to targets of unknown range (Ref. 7). The limited experiment suggests that perhaps the sure region may in fact be narrower than modeled.

(2) "Cookie Cutter" probability separation between max and min error regions is not an accurate representation, for error probability distributions would be bivariate. It is unlikely that a round impacting far short or over would ever be called doubtful.

The author does not claim that Model 1 or Model 2 may be the valid one to use. Unfortunately, apparently no one has seen the need to invest in conducting observer capability experiments to precisely ascertain what the magnitudes of observer errors in spotting quadrant location of bursts are.

APPENDIX B: SAMPLE COMPUTATIONS OF A PRECISION REGISTRATION USING THE ROBBINS-MONRO PROPOSED TECHNIQUE WITH FORK RECURSIVE CONSTANT

The purpose of this appendix is to show how the proposed Robbins-Monro technique is used to compute the adjusted quadrant elevation of a hypothetical precision registration. The example will treat most of the decision steps which may arise as a result of firing. A hypothetical computation form will be presented; the numbered comments appearing after the form are keyed to the circled numbers appearing in the table.

FORK=8 ① PER=20 ① N=3 ①

ANGLE T=0mils

ROUND	N	FORK/N	ELEVATION	FDC RANGE SPOT	FO RANGE SPOT
1			300.0	+	+
2	3 ②	8/3=-2.7	297.3	+	+
3	3 ③	-2.7	294.6	⊖	-
4	4 ④	8/4=+2.0	296.6	?	?
5	⑤		296.6	⊕	+
6	5 ⑥	8/5=-1.6	295.0	TGT	TGT
7	6 ⑦		295.0	⊖	-
8	7	8/7=+1.1	296.1	⊕	+
9	8 ⑧	8/8=-1.0	295.1	⊖	-
	⑨	END OF MISSION			
	9	8/9=+0.9	296.0 = The adjusted QE		

1. When the observer splits a 100 meter bracket and thus enters into the fire for effect phase, the value of FORK and PER are extracted from the firing tables. The initial iteration number "N" is established and is based on the value of PER. In the example presented, since the PER is greater than 18 meters, the initial value of N is 3.

2. The first round in the fire for effect phase resulted in an OVER observer spot. Since the Angle T = 0 mils, the fire direction center range spot is also OVER. FDC applies an opposite elevation correction based on the initial FORK/N value and continues to apply this correction to all FDC positive range spots till the initial FORK/N bracket is achieved.

3. In (2) the initial FORK/N bracket was not attained; the previous FORK/N correction is applied until the bracket is established.

4. After the initial FORK/N bracket has been achieved, N is advanced by 1 each time an FDC range spot is attained. In the example the value of N is now 4. FORK/N is computed using the new value of N and applied appropriately to the previous elevation fired.

5. As a result of applying correction in (4) a doubtful FDC range spot has been attained. The round is refired using same data as for last round. N is NOT advanced by 1; N is advanced ONLY after attainment of an FDC positive range spot.

6. The correction applied in this step resulted in a target hit.

7. A TARGET hit is a 'neutral' FDC positive range spot; N is advanced by 1 (N=6 now). NO correction to data is applied, the same elevation as for the previous round is used. The only difference in handling a DOUBTFUL and TARGET spot is that N is NOT advanced after a DOUBTFUL but is after a TARGET.

8. Based on the corrections applied in this step, the equivalent number of FDC positive range spot usable rounds as for the FM 6-40 procedure have been attained (6 positive sensed rounds) and the mission is terminated.

9. The computation of adjusted elevation is accomplished by advancing N by 1 (N=9) and applying the FORK/N correction appropriately based on the last FDC positive range spot round. This step completes the computational portion for determining the adjusted elevation of the precision registration.

APPENDIX C: TABULATED RESULTS OF DIRECT COMPARISON OF FM 6-40 AND ROBBINS-MONRO 1 ROUND PRECISION REGISTRATION

The tabulated results presented are from computer simulation comparison as described in Section III,D. Pages 104 to 113 contain the results under forward observer spot capability model #1. Pages 114 to 123 show the results under conditions of observer spot capability model #2 with maximum error region probability p=0.05; pages 124 to 133 tabulate the results when maximum error probability is p=0.25. The abbreviations used in the tables are as follow:

C -The FM 6-40 precision registration

RM -The Robbins-Monro 1 round type recommended precision fire procedure. The associated number refers to the number of fire direction center fire for effect positive range spot rounds (to include the last initial bracket round) in computing registration adjusted elevation.

RAD -The average radial miss distance in meters of estimate of true target center.

AMRG-The average absolute miss distance range in meters.

AMDF-The average absolute miss distance in deviation in meters.

FFERDS-The average fire for effect rounds used.

SDRG-The standard deviation of the range miss component.

SDDF-The standard deviation of the deflection miss component.

SDRD-The standard deviation of the fire for effect rounds.

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 5GB   RANGE: 2000M   PER: 7M   PED: 1M

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	6.30	5.09	6.33	3.50	4.33	7.17	0.85
RM3	5.97	5.19	6.56	2.91	3.45	4.57	1.17
RM4	5.30	4.58	5.78	2.67	3.19	5.60	1.18
RM5	4.93	4.23	5.34	2.61	3.12	6.63	1.20
RM6	4.56	3.92	4.88	2.43	2.95	7.65	1.20

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	6.15	5.46	6.92	2.80	3.45	7.06	0.89
RM3	6.64	6.03	7.53	2.78	3.49	4.34	0.96
RM4	5.73	5.16	6.43	2.59	3.19	5.34	0.96
RM5	5.09	4.56	5.74	2.39	2.95	6.34	0.96
RM6	4.68	4.19	5.29	2.30	2.80	7.34	0.96

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	6.13	5.59	7.10	2.60	3.22	7.64	2.60
RM3	6.04	5.57	7.04	2.47	3.19	4.37	0.87
RM4	5.47	5.05	6.30	2.30	2.99	5.37	0.87
RM5	4.97	4.66	5.78	2.05	2.59	6.37	0.87
RM6	4.45	4.24	5.28	1.85	2.30	7.37	0.87

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 5GB RANGE: 2000M PER: 7M PED: 1M

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	6.37	5.62	7.18	2.86	4.19	8.36	1.94
RM3	6.83	5.78	7.16	3.41	4.58	4.31	0.81
RM4	5.86	5.06	6.24	2.91	3.92	5.31	0.81
RM5	5.10	4.49	5.56	2.52	3.37	6.31	0.81
RM6	4.61	4.09	5.03	2.29	3.09	7.32	0.81

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	5.81	5.18	6.49	2.63	3.73	8.99	1.81
RM3	6.73	5.17	6.51	3.88	5.99	4.96	1.20
RM4	5.44	4.50	5.58	2.95	4.38	6.02	1.22
RM5	5.11	4.33	5.44	2.67	4.07	7.05	1.22
RM6	4.53	4.00	4.96	2.29	3.31	8.07	1.23

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	6.33	6.15	7.59	1.95	3.93	8.19	1.46
RM3	7.03	6.26	7.85	2.80	4.73	4.06	0.57
RM4	5.57	5.16	6.58	2.17	3.49	5.06	0.57
RM5	4.91	4.70	5.98	1.79	2.60	6.06	0.57
RM6	4.37	4.21	5.32	1.66	2.61	7.06	0.57

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 5GB RANGE: 6000M PER: 13M PED: 3M

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	10.84	9.13	11.29	5.05	6.34	7.24	0.85
RM3	11.18	9.96	12.26	4.43	5.60	4.66	1.14
RM4	10.31	9.05	11.29	4.39	5.38	5.72	1.19
RM5	9.54	8.22	10.17	4.24	5.37	6.79	1.21
RM6	8.78	7.21	9.00	4.26	5.40	7.85	1.22

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	10.67	9.37	11.61	4.47	5.62	7.02	0.70
RM3	11.36	10.28	12.96	4.25	5.33	4.36	0.95
RM4	10.64	9.58	11.89	4.13	5.14	5.36	0.95
RM5	9.96	9.06	11.17	3.74	4.76	6.36	0.95
RM6	9.23	8.18	10.13	3.87	4.83	7.36	0.95

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	10.20	9.00	11.43	4.15	5.58	7.27	1.06
RM3	11.13	10.15	12.67	4.05	5.12	4.39	0.87
RM4	9.97	8.92	11.06	4.01	5.06	5.39	0.87
RM5	9.22	8.18	10.38	3.77	4.84	6.39	0.87
RM6	9.04	8.11	10.06	3.67	4.59	7.39	0.87

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 5GB RANGE: 6000M PER: 13M PED: 3M

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	11.43	9.50	11.67	5.38	8.21	8.28	1.82
RM3	12.32	10.15	12.66	5.99	7.74	4.40	0.83
RM4	10.51	8.66	10.89	5.15	6.88	5.40	0.83
RM5	9.70	8.22	10.30	4.43	5.90	6.40	0.83
RM6	8.87	7.55	9.54	4.04	5.37	7.40	0.83

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	11.09	8.67	10.90	5.66	9.70	9.52	4.38
RM3	12.23	9.93	12.44	5.95	7.89	5.03	1.17
RM4	10.95	8.91	11.37	5.30	7.14	6.12	1.19
RM5	9.90	8.31	10.30	4.64	6.33	7.22	1.21
RM6	9.40	7.93	9.87	4.41	5.93	8.27	1.23

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	10.33	9.25	11.51	3.74	10.97	7.89	1.34
RM3	12.60	10.34	12.90	5.60	9.00	4.20	0.62
RM4	11.31	9.52	11.81	4.87	7.67	5.20	0.62
RM5	9.80	8.47	10.72	4.06	5.83	6.20	0.62
RM6	8.99	8.01	10.00	3.56	5.13	7.20	0.62

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 3M

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	15.67	14.47	18.25	4.98	6.12	7.12	0.71
RM3	15.27	14.45	18.25	4.11	5.18	4.63	1.13
RM4	14.30	13.38	16.67	4.41	5.39	5.66	1.15
RM5	13.33	12.33	15.46	4.16	5.23	6.70	1.16
RM6	12.45	11.36	14.29	4.37	5.37	7.75	1.18

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	15.37	14.51	18.36	4.31	5.78	7.17	0.96
RM3	15.80	15.24	18.67	3.85	4.94	4.51	1.04
RM4	14.59	14.01	17.17	3.70	4.74	5.51	1.04
RM5	13.11	12.49	15.47	3.70	4.68	6.51	1.04
RM6	12.37	11.65	14.52	3.69	4.65	7.51	1.04

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	15.61	13.99	17.75	5.29	7.74	8.23	1.78
RM3	15.99	15.07	18.92	4.53	5.78	4.59	0.95
RM4	15.09	14.36	17.56	4.11	5.30	5.59	0.95
RM5	13.71	13.05	16.38	3.79	4.86	6.59	0.95
RM6	12.88	12.23	15.32	3.69	4.66	7.59	0.95

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 3M

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	16.84	13.73	17.24	7.62	12.30	9.79	3.24
RM3	17.39	14.98	18.67	7.12	9.12	4.50	0.90
RM4	15.44	13.38	16.52	6.38	8.26	5.50	0.90
RM5	14.21	12.40	15.37	5.67	7.53	6.50	0.90
RM6	13.61	12.11	14.94	5.23	6.92	7.50	0.90

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	16.87	13.27	16.48	8.16	14.79	10.51	3.93
RM3	16.30	13.67	16.90	7.28	9.25	5.00	1.17
RM4	14.97	12.55	15.64	6.69	8.52	6.07	1.19
RM5	14.52	12.19	15.12	6.31	8.22	7.12	1.21
RM6	13.53	11.51	14.39	5.70	7.52	8.18	1.23

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	15.08	14.56	18.29	3.46	5.30	8.67	1.59
RM3	16.45	14.44	17.79	6.06	8.94	4.39	0.81
RM4	14.78	13.35	16.66	4.95	7.14	5.39	0.81
RM5	13.56	12.21	15.18	4.58	7.42	6.39	0.81
RM6	12.35	11.41	13.99	3.97	5.75	7.39	0.81

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 6WB   RANGE: 8000M   PER: 27M   PED: 4M

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	20.20	18.57	23.29	6.26	7.73	7.11	0.69
RM3	20.29	19.02	23.64	5.61	7.10	4.67	1.16
RM4	18.99	17.57	22.17	5.76	7.03	5.71	1.18
RM5	17.79	16.31	20.35	5.69	7.08	6.75	1.20
RM6	17.70	16.15	20.11	5.74	6.99	7.80	1.23

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	21.13	19.64	24.36	5.95	8.55	7.25	1.09
RM3	21.70	20.54	25.61	5.58	6.96	4.53	0.92
RM4	21.06	19.95	24.72	5.46	6.88	5.53	0.92
RM5	18.79	17.59	21.84	5.29	6.80	6.53	0.92
RM6	17.64	16.50	20.76	5.08	6.39	7.53	0.92

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	21.60	19.15	24.10	7.53	11.06	8.18	1.81
RM3	20.84	19.23	24.11	6.17	7.77	4.51	0.89
RM4	19.97	18.54	23.17	5.80	7.33	5.51	0.89
RM5	18.75	17.62	22.17	5.32	6.68	6.51	0.89
RM6	17.37	16.21	20.37	5.08	6.36	7.51	0.89

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 6WB RANGE: 8000M PER: 27M PED: 3M

ANGLE T: 600m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	26.23	18.54	23.21	14.52	23.62	9.88	2.65
RM3	23.36	20.18	24.78	9.13	12.39	4.46	0.78
RM4	20.67	18.12	22.53	7.83	10.49	5.46	0.78
RM5	18.71	16.40	20.77	7.05	9.28	6.46	0.78
RM6	17.58	15.49	19.34	6.70	8.76	7.46	0.78

ANGLE T: 800m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	23.14	18.15	22.88	11.31	17.11	10.55	2.67
RM3	22.33	18.21	22.89	10.21	13.09	5.00	1.12
RM4	21.34	17.72	22.09	9.41	12.30	6.08	1.13
RM5	19.82	16.40	20.34	8.90	11.70	7.17	1.15
RM6	18.56	15.33	19.21	8.27	10.92	8.24	1.17

ANGLE T: 1600m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	20.36	18.83	23.52	5.59	13.70	8.17	1.48
RM3	22.45	20.19	24.82	7.40	10.11	4.39	0.75
RM4	20.77	19.00	23.36	6.43	8.92	5.39	0.75
RM5	18.97	17.55	22.10	5.39	7.51	6.39	0.75
RM6	17.91	16.68	21.09	4.96	6.88	7.39	0.75

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 6WB RANGE: 10000M PER: 34M PED: 5M

ANGLE T: 10m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	23.61	21.81	27.27	6.89	8.77	7.14	0.67
RM3	26.56	24.88	31.20	6.81	8.58	4.58	1.00
RM4	24.78	22.85	28.47	7.24	8.89	5.63	1.04
RM5	23.45	21.64	26.73	7.05	8.77	6.68	1.06
RM6	21.89	19.84	25.05	7.21	8.89	7.72	1.07

ANGLE T: 200m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	26.24	24.12	30.64	7.87	11.54	7.45	1.31
RM3	26.30	24.71	30.67	6.80	8.63	4.45	0.87
RM4	23.67	22.13	27.61	6.49	8.39	5.45	0.87
RM5	21.79	20.43	25.57	6.27	7.92	6.45	0.87
RM6	20.58	19.12	24.34	6.00	7.53	7.45	0.87

ANGLE T: 400m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	26.09	23.07	28.94	9.31	13.15	8.39	1.80
RM3	26.56	24.74	31.20	7.30	9.36	4.47	0.82
RM4	25.27	23.49	29.34	7.15	9.00	5.47	0.82
RM5	22.90	21.27	26.74	6.50	8.21	6.47	0.82
RM6	22.77	21.13	26.23	6.34	8.21	7.47	0.82

FORWARD OBSERVER ERROR MODEL NUMBER 1

CHARGE: 6WB   RANGE: 10000M   PER: 34M   PED: 5M

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	34.96	24.69	30.55	19.29	30.73	9.98	2.75
RM3	28.10	24.34	30.31	10.60	14.05	4.45	0.79
RM4	25.86	22.73	28.44	9.25	12.33	5.45	0.79
RM5	24.19	21.37	26.74	8.57	11.20	6.45	0.79
RM6	22.31	19.78	24.85	7.96	10.36	7.45	0.79

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	29.74	22.83	28.50	15.04	22.01	10.91	2.38
RM3	28.11	23.38	29.07	12.23	15.93	4.99	1.16
RM4	25.82	21.60	26.81	10.86	14.35	6.12	1.22
RM5	24.53	20.41	25.45	10.41	13.98	7.21	1.24
RM6	23.64	19.61	24.51	9.96	13.45	8.30	1.28

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	25.15	23.83	29.82	6.01	8.28	8.78	1.58
RM3	26.35	23.64	29.92	8.77	11.96	4.38	0.72
RM4	24.97	22.69	28.25	7.81	10.56	5.38	0.72
RM5	22.75	20.79	26.34	6.94	9.52	6.38	0.72
RM6	21.69	20.01	24.81	6.47	8.67	7.38	0.72

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5GB   RANGE: 2000M   PER: 7M   PED: 1M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	6.74	5.62	7.37	3.51	4.29	7.41	1.21
RM3	7.74	7.06	11.48	3.01	3.62	4.79	1.61
RM4	7.00	6.31	10.46	2.86	3.43	5.84	1.64
RM5	6.47	5.68	9.64	2.82	3.39	6.89	1.65
RM6	5.99	5.33	9.15	2.71	3.22	7.93	1.67

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	6.75	5.94	7.72	3.07	4.33	7.19	0.93
RM3	8.47	7.86	10.91	3.10	4.30	4.52	1.30
RM4	7.43	6.89	9.59	2.80	3.91	5.52	1.30
RM5	6.54	6.04	8.57	2.56	3.52	6.52	1.30
RM6	5.92	5.49	7.92	2.36	3.21	7.53	1.30

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	6.84	6.20	8.14	2.77	4.27	7.40	1.32
RM3	8.59	7.53	10.92	3.60	8.69	4.52	1.44
RM4	7.52	6.61	9.74	3.25	8.35	5.52	1.44
RM5	6.73	5.88	8.88	2.98	8.00	6.52	1.44
RM6	5.99	5.25	8.24	2.70	7.69	7.52	1.44

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE 5GB RANGE: 2000M PER: 7M PED: 1M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 600m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	8.73	7.53	10.47	3.83	8.48	8.39	2.03
RM3	9.25	7.47	10.74	4.86	8.73	4.48	1.10
RM4	8.05	6.58	9.61	4.22	8.08	5.48	1.10
RM5	7.17	5.96	8.61	3.65	7.53	6.48	1.10
RM6	6.58	5.52	8.07	3.38	7.19	7.48	1.10

ANGLE T: 800m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	7.22	5.80	7.38	3.92	7.50	9.64	3.13
RM3	8.53	6.50	9.11	4.96	8.69	5.35	2.20
RM4	7.27	5.63	8.03	4.29	7.87	6.49	2.26
RM5	6.54	5.16	7.36	3.75	6.91	7.62	2.42
RM6	5.82	4.68	6.73	3.34	6.40	8.74	2.50

ANGLE T: 1600m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	8.61	6.97	9.08	3.94	8.11	7.45	1.07
RM3	10.89	6.87	8.92	7.11	12.39	4.06	0.61
RM4	9.10	5.93	7.76	5.72	10.62	5.06	0.61
RM5	7.79	5.28	6.99	4.76	9.56	6.06	0.61
RM6	7.10	4.91	6.48	4.27	8.92	7.06	0.61

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5GB   RANGE: 6000M   PER: 13M   PED: 3M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 100

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	11.25	9.79	12.45	4.74	5.97	7.45	1.05
RM3	12.62	11.43	14.90	4.59	5.66	4.87	1.45
RM4	11.29	10.01	13.06	4.48	5.60	5.95	1.46
RM5	10.70	9.18	11.90	4.77	5.86	7.04	1.48
RM6	10.01	8.73	11.03	4.38	5.48	8.13	1.51

ANGLE T: 2000

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	12.14	10.67	14.03	4.93	6.84	7.14	0.79
RM3	12.87	11.61	15.30	4.58	5.96	4.51	1.15
RM4	11.90	10.66	13.94	4.53	5.76	5.51	1.15
RM5	10.90	9.70	12.55	4.30	5.43	6.51	1.15
RM6	10.15	9.07	11.81	4.12	5.17	7.51	1.15

ANGLE T: 4000

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	12.67	11.06	14.43	5.21	7.27	7.28	1.08
RM3	12.46	11.00	14.49	5.00	7.49	4.50	1.14
RM4	11.40	10.11	13.31	4.59	6.84	5.50	1.14
RM5	10.44	9.26	12.21	4.20	6.27	6.50	1.14
RM6	9.64	8.45	11.27	4.08	5.89	7.50	1.14

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE:5GB   RANGE: 6000M   PER: 13M   PED: 3M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 600m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	13.25	10.87	14.07	6.12	9.35	8.28	2.05
RM3	14.85	11.95	16.64	7.41	11.50	4.53	1.09
RM4	13.47	10.93	15.20	6.65	10.77	5.53	1.09
RM5	12.41	10.31	14.43	5.84	9.80	6.53	1.09
RM6	11.50	9.54	13.33	5.44	9.39	7.53	1.09

ANGLE T: 800m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	12.30	9.38	12.01	6.61	10.48	9.59	2.17
RM3	13.45	10.67	13.67	7.01	9.61	5.52	1.98
RM4	12.35	9.78	12.44	6.49	9.17	6.66	2.00
RM5	11.07	9.06	11.66	5.48	7.85	7.84	2.05
RM6	10.25	8.46	10.82	5.04	7.30	8.97	2.09

ANGLE T: 1600m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	14.39	10.62	13.56	7.72	12.72	7.25	0.88
RM3	16.31	10.84	13.61	10.16	16.18	4.30	0.61
RM4	13.79	9.36	12.02	8.37	13.77	5.30	0.61
RM5	12.33	8.70	10.95	7.32	12.41	6.30	0.61
RM6	11.55	8.61	10.84	6.37	11.02	7.30	0.61

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 3M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 10m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	16.63	15.29	19.55	5.39	6.64	7.33	1.03
RM3	16.41	15.55	20.31	4.41	5.48	4.90	1.39
RM4	15.35	14.44	18.92	4.30	5.34	5.97	1.39
RM5	13.78	12.80	16.99	4.21	5.25	7.03	1.43
RM6	13.46	12.33	16.11	4.56	5.63	8.10	1.45

ANGLE T: 200m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	17.51	16.33	21.37	5.13	8.46	7.12	8.46
RM3	15.97	15.14	19.09	4.44	5.80	4.60	1.19
RM4	14.84	13.98	17.63	4.32	5.65	5.60	1.19
RM5	13.88	13.05	16.53	4.04	5.16	6.60	1.19
RM6	12.96	12.29	15.49	3.81	4.79	7.60	1.19

ANGLE T: 400m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	17.15	15.54	19.81	5.57	7.96	7.72	1.52
RM3	17.81	16.42	26.24	5.60	10.25	4.64	1.28
RM4	16.38	15.11	24.68	5.08	9.70	5.64	1.28
RM5	15.04	13.88	23.40	4.82	9.34	6.64	1.28
RM6	14.15	13.19	22.42	4.33	8.56	7.64	1.28

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 3M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	20.64	16.89	22.74	9.19	15.59	9.41	2.81
RM3	21.00	16.24	20.54	10.88	15.37	4.62	1.12
RM4	18.37	14.43	18.44	9.16	13.16	5.62	1.12
RM5	16.66	13.30	16.83	8.11	12.17	6.62	1.12
RM6	15.31	12.08	15.57	7.56	11.70	7.62	1.12

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	17.86	14.11	18.03	8.66	13.46	10.88	3.71
RM3	20.12	14.73	18.73	11.22	16.28	5.81	2.10
RM4	17.59	13.16	16.86	9.72	14.22	6.99	2.16
RM5	15.95	12.35	15.60	8.41	12.68	8.18	2.24
RM6	14.66	11.51	14.69	7.48	11.05	9.36	2.31

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	19.84	15.99	20.48	8.55	15.97	7.37	0.93
RM3	21.59	14.70	18.24	12.47	21.33	4.45	0.77
RM4	19.10	13.52	16.80	10.47	18.82	5.45	0.77
RM5	17.10	12.16	15.24	9.31	16.81	6.45	0.77
RM6	15.43	11.45	14.55	7.90	14.86	7.45	0.77

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 6 RANGE: 8000M PER: 27M PED: 4M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	21.44	19.96	25.77	6.05	7.55	7.30	0.80
RM3	20.69	19.24	25.00	5.92	7.52	4.82	1.26
RM4	19.73	18.13	23.32	6.24	7.64	5.88	1.28
RM5	18.65	17.01	21.87	5.94	7.37	6.95	1.31
RM6	17.81	16.35	20.62	5.83	7.15	8.01	1.32

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	22.88	21.30	27.19	6.43	9.66	7.18	1.02
RM3	23.49	22.29	34.14	5.67	8.15	4.48	0.99
RM4	21.57	20.55	31.93	5.56	8.00	5.48	0.99
RM5	20.07	18.91	30.65	5.37	7.68	6.48	0.99
RM6	19.77	18.72	20.70	5.40	7.39	7.48	0.99

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	23.07	20.99	27.30	7.32	11.21	7.66	1.36
RM3	22.42	20.62	26.24	6.84	9.37	4.57	1.03
RM4	21.16	19.50	24.43	6.43	8.63	5.57	1.03
RM5	19.14	17.53	22.21	6.12	8.18	6.57	1.03
RM6	18.67	17.20	21.31	5.92	7.68	7.57	1.03

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 6   RANGE: 8000M   PER: 27M   PED: 4M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	31.09	23.65	33.03	15.55	25.87	9.62	2.64
RM3	24.95	20.80	26.52	11.02	15.29	4.59	1.03
RM4	23.35	19.81	25.25	9.81	13.44	5.59	1.03
RM5	22.00	19.05	24.03	8.81	12.20	6.59	1.03
RM6	20.95	18.39	22.94	8.12	10.99	7.59	1.03

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	24.66	19.06	24.43	12.25	18.09	10.91	2.65
RM3	25.02	19.90	25.13	12.02	16.36	5.48	1.73
RM4	22.84	18.37	23.00	10.94	14.87	6.64	1.78
RM5	20.95	16.67	21.07	10.11	13.87	7.79	1.85
RM6	19.53	15.72	19.45	9.36	12.70	8.93	1.89

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	25.00	20.97	26.19	10.07	16.07	7.15	0.67
RM3	26.22	20.68	25.75	12.00	21.94	4.47	0.78
RM4	23.88	19.34	24.13	10.10	19.04	5.47	0.78
RM5	21.84	17.96	22.51	8.83	17.30	6.47	0.78
RM6	21.05	17.83	21.55	8.12	15.77	7.47	0.78

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 6   RANGE: 10000M   PER: 34M   PED: 5M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	25.43	23.71	30.47	6.99	8.74	7.31	0.81
RM3	26.37	24.64	31.33	7.08	8.93	4.79	1.24
RM4	25.61	23.83	29.90	7.24	8.81	5.87	1.26
RM5	23.31	21.71	26.82	6.77	8.44	6.93	1.29
RM6	21.22	19.41	24.27	6.99	8.52	8.00	1.32

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	29.73	27.88	35.47	7.73	10.83	7.22	1.03
RM3	28.92	27.20	33.68	7.47	9.61	4.54	0.89
RM4	26.13	24.51	30.91	6.94	9.04	5.54	0.89
RM5	24.62	22.97	29.08	6.81	8.67	6.54	0.89
RM6	23.83	22.26	28.00	6.74	8.58	7.54	0.89

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	29.61	26.56	34.69	9.36	13.71	7.83	1.57
RM3	28.48	26.09	32.32	8.64	11.57	4.53	0.96
RM4	25.85	23.77	30.39	7.65	10.34	5.53	0.96
RM5	24.23	22.26	28.26	7.27	9.69	6.53	0.96
RM6	22.97	20.84	26.28	7.27	9.64	7.53	0.96

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 6   RANGE: 10000M   PER: 34M   PED: 5M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.05

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	38.62	28.33	37.15	20.25	30.56	9.71	2.60
RM3	32.03	27.10	33.80	13.18	17.81	4.51	0.86
RM4	29.37	25.23	31.66	11.66	15.81	5.51	0.86
RM5	27.41	23.49	29.58	10.86	14.39	6.51	0.86
RM6	25.46	22.12	27.75	9.94	13.04	7.51	0.86

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	30.57	23.86	29.96	15.12	21.50	11.13	2.36
RM3	30.67	24.29	30.06	14.36	20.01	5.50	1.52
RM4	27.98	22.34	27.63	13.14	18.07	6.70	1.65
RM5	25.81	20.45	25.50	12.22	16.63	7.86	1.70
RM6	24.25	19.46	24.51	11.31	15.54	9.08	1.79

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	30.76	25.44	32.57	11.76	35.95	7.19	0.87
RM3	31.06	24.96	31.46	13.62	19.70	4.48	0.73
RM4	28.04	23.45	29.33	11.37	16.74	5.48	0.73
RM5	26.18	22.25	27.33	10.20	15.16	6.58	0.73
RM6	24.51	20.85	26.20	9.48	13.95	7.58	0.73

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5GB RANGE: 2000M PER: 7M PED: 1M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 10m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	7.45	6.33	8.22	3.67	4.50	7.48	1.25
RM3	7.94	7.28	12.65	2.99	3.59	4.89	1.75
RM4	6.86	6.20	11.55	2.80	3.34	5.94	1.77
RM5	6.27	5.57	10.77	2.76	3.29	6.99	1.80
RM6	5.80	5.14	10.31	2.66	3.17	8.05	1.83

ANGLE T: 200m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	7.69	7.07	9.20	2.94	4.10	7.11	0.92
RM3	8.50	8.01	11.60	2.80	3.75	4.55	1.41
RM4	7.55	7.06	10.38	2.68	3.49	5.55	1.41
RM5	6.80	6.34	9.22	2.52	3.27	6.55	1.41
RM6	6.24	5.81	8.55	2.38	3.12	7.55	1.41

ANGLE T: 400m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	9.25	8.52	13.37	3.19	10.80	7.39	1.37
RM3	9.05	8.60	12.69	2.94	4.93	4.50	1.14
RM4	7.99	7.69	11.49	2.53	4.52	5.50	1.14
RM5	6.97	6.74	10.36	2.27	4.06	6.50	1.14
RM6	6.32	6.13	9.67	2.04	3.76	7.50	1.14

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5GB RANGE: 2000M PER: 7M PED: 1M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	12.50	11.10	17.47	4.69	15.61	8.35	2.00
RM3	10.70	9.24	13.48	4.76	7.69	4.50	1.18
RM4	9.68	8.41	12.32	4.14	6.92	5.50	1.18
RM5	8.74	7.74	11.32	3.61	6.33	6.50	1.18
RM6	8.13	7.32	10.79	3.18	5.86	7.50	1.18

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	9.18	6.98	10.40	5.47	11.28	10.62	8.05
RM3	9.96	7.13	10.10	6.27	10.26	5.81	3.11
RM4	8.64	6.31	8.88	5.39	8.92	7.05	3.47
RM5	7.45	5.55	8.04	4.64	7.93	8.30	3.70
RM6	6.63	5.09	7.38	4.09	7.11	9.49	3.80

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	16.36	6.97	9.23	13.53	20.60	7.35	1.07
RM3	17.36	7.08	9.22	14.49	25.69	4.10	0.58
RM4	15.46	6.37	8.17	12.96	23.57	5.10	0.58
RM5	14.19	5.74	7.46	12.03	21.98	6.10	0.58
RM6	13.28	5.25	6.87	11.34	21.79	7.10	0.58

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5GB RANGE: 6000M PER: 13M PED: 3M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 10m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	11.72	10.18	13.34	4.89	6.32	7.49	1.13
RM3	12.66	11.41	14.53	4.54	5.65	4.86	1.46
RM4	11.74	10.35	13.03	4.63	5.79	5.93	1.47
RM5	10.89	9.55	11.92	4.54	5.66	7.03	1.50
RM6	10.59	9.13	11.39	4.57	5.70	8.13	1.52

ANGLE T: 200m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	12.74	11.34	16.31	4.86	6.26	7.04	0.72
RM3	13.76	12.82	16.87	4.37	5.80	4.55	1.19
RM4	12.41	11.33	15.24	4.38	5.75	5.55	1.19
RM5	11.52	10.40	14.12	4.30	5.68	6.55	1.19
RM6	10.79	9.66	13.13	4.23	5.51	7.55	1.19

ANGLE T: 400m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	14.06	12.78	16.31	4.95	7.27	7.19	0.97
RM3	14.33	13.06	16.76	4.98	6.54	4.54	1.09
RM4	12.65	11.64	14.97	4.31	5.71	5.54	1.09
RM5	11.75	10.83	13.81	4.11	5.36	6.54	1.09
RM6	10.73	9.81	12.74	3.89	4.96	7.54	1.09

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5GB   RANGE: 6000M   PER: 13M   PED: 3M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 600m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	18.75	16.54	22.97	7.08	12.80	8.15	2.35
RM3	16.91	13.93	18.69	8.36	12.56	4.56	1.11
RM4	15.45	12.74	16.96	7.52	11.41	5.56	1.11
RM5	13.99	11.50	15.24	6.81	10.32	6.56	1.11
RM6	13.34	11.12	14.50	6.27	9.45	7.56	1.11

ANGLE T: 800m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	14.36	10.18	13.08	8.66	13.91	10.24	3.15
RM3	15.79	12.10	15.12	8.91	12.44	5.92	2.09
RM4	13.85	10.53	13.42	7.86	10.88	7.20	2.15
RM5	12.75	9.99	12 54	6.98	9.87	8.45	2.20
RM6	11.84	9.45	11.85	6.30	8.86	9.71	2.27

ANGLE T: 1600m̸

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	25.19	10.61	13.79	20.78	29.45	7.22	0.84
RM3	25.14	11.32	14.12	20.27	28.98	4.25	0.66
RM4	22.38	10.12	12.81	17.90	25.79	5.25	0.66
RM5	20.29	9.66	11.96	15.99	23.19	6.25	0.66
RM6	19.03	9.26	11.47	14.70	21.59	7.25	0.66

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 3M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	16.57	15.42	19.82	4.98	6.12	7.33	0.97
RM3	16.80	15.80	24.89	4.54	5.64	4.88	1.64
RM4	15.57	14.62	23.27	4.46	5.55	5.94	1.68
RM5	14.58	13.60	22.31	4.35	5.42	7.00	1.70
RM6	14.04	13.12	21.31	4.28	5.35	8.06	1.71

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	17.49	16.63	22.07	4.62	6.30	7.13	0.89
RM3	17.09	16.26	20.74	4.30	5.57	4.64	1.20
RM4	15.69	14.99	19.01	4.03	5.25	5.64	1.20
RM5	14.52	13.88	17.62	3.82	4.87	6.64	1.20
RM6	13.33	12.62	15.85	3.87	4.91	7.64	1.20

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	20.08	18.98	25.29	5.35	7.94	7.67	1.56
RM3	19.19	18.05	25.02	5.47	10.13	4.75	1.34
RM4	17.16	15.92	20.70	5.23	9.48	5.75	1.34
RM5	15.31	14.25	18.78	4.63	8.78	6.75	1.34
RM6	14.65	13.76	17.84	4.25	8.45	7.75	1.34

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 3M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	29.40	26.05	39.06	10.03	18.19	9.43	4.17
RM3	24.16	19.13	25.78	12.09	17.86	4.68	1.19
RM4	22.24	17.56	23.93	11.13	17.35	5.68	1.19
RM5	21.10	16.86	23.08	10.31	16.53	6.68	1.19
RM6	19.36	15.94	21.70	8.98	14.87	7.68	1.19

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	21.20	16.23	21.02	11.61	18.70	11.16	4.34
RM3	22.25	16.12	20.45	12.77	17.34	6.39	2.19
RM4	18.97	14.15	17.81	10.72	15.01	7.69	2.28
RM5	17.19	12.99	16.53	9.51	13.31	9.02	2.37
RM6	16.01	12.33	15.35	8.65	12.26	10.28	2.47

ANGLE T:1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	32.65	15.58	19.95	25.00	36.32	7.46	1.05
RM3	31.34	14.98	18.80	24.02	34.23	4.43	0.82
RM4	29.31	14.40	17.80	22.28	31.65	5.43	0.82
RM5	27.14	13.12	16.34	20.90	29.65	6.43	0.82
RM6	25.55	12.78	15.82	19.45	27.70	7.43	0.82

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 6 RANGE: 8000M PER: 27M PED: 4M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 10₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	21.36	19.91	25.19	6.02	8.09	7.32	0.84
RM3	23.42	22.12	29.18	5.81	7.26	4.83	1.21
RM4	21.91	20.56	27.13	6.08	7.44	5.89	1.25
RM5	20.95	19.59	25.62	5.78	7.19	6.95	1.29
RM6	19.09	17.67	23.48	5.71	7.04	8.03	1.32

ANGLE T: 200₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	23.42	22.03	28.31	6.25	8.27	7.17	0.87
RM3	23.51	22.17	28.23	5.98	8.01	4.67	1.16
RM4	21.38	20.11	25.69	5.51	7.35	5.67	1.16
RM5	18.80	17.69	22.37	5.26	6.91	6.67	1.16
RM6	17.74	16.58	21.26	5.11	6.59	7.67	1.16

ANGLE T: 400₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	25.01	23.20	30.29	7.26	10.30	7.46	1.20
RM3	24.51	22.85	30.00	7.21	10.89	4.62	1.08
RM4	22.85	21.31	28.19	6.65	9.73	5.62	1.08
RM5	20.49	19.02	25.31	6.16	8.84	6.62	1.08
RM6	19.79	18.55	24.62	5.75	8.46	7.62	1.08

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 6 RANGE: 8000M PER: 27M PED: 4M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	47.75	41.18	64.20	17.99	31.89	9.53	3.02
RM3	30.71	25.96	33.07	12.72	17.34	4.65	1.03
RM4	27.58	23.58	30.41	11.28	15.39	5.65	1.03
RM5	24.70	21.22	27.63	10.09	13.50	6.65	1.03
RM6	22.99	19.97	25.90	9.07	12.13	7.65	1.03

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	27.89	20.86	26.40	15.37	21.12	11.03	3.03
RM3	27.44	20.57	25.71	15.22	20.13	6.23	2.15
RM4	26.02	20.09	24.59	13.64	18.12	7.62	2.30
RM5	23.59	18.13	22.11	12.54	16.82	8.97	2.40
RM6	21.68	16.84	21.20	11.27	15.39	10.25	2.46

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	41.32	19.82	25.79	31.64	44.54	7.21	0.79
RM3	37.89	29.59	25.84	27.10	36.54	4.45	0.78
RM4	35.12	19.05	23.74	25.37	34.71	5.45	0.78
RM5	33.24	18.07	22.69	23.86	32.70	6.45	0.78
RM6	30.62	16.82	21.24	21.88	30.18	7.45	0.78

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 6 RANGE: 10000M PER: 34M PED: 5M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 100

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	27.63	25.84	32.40	7.31	9.25	7.30	0.88
RM3	27.20	25.72	33.35	6.79	8.48	4.80	1.24
RM4	26.21	24.31	31.38	7.61	9.37	5.86	1.26
RM5	24.39	22.56	29.32	6.78	8.53	6.93	1.28
RM6	23.17	21.23	27.52	7.26	8.81	8.00	1.30

ANGLE T: 2000

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	29.45	27.58	35.77	7.81	10.63	7.17	0.89
RM3	29.28	27.66	34.47	7.15	9.17	4.56	0.96
RM4	27.09	25.49	31.76	6.93	8.88	5.56	0.96
RM5	25.51	24.06	30.20	6.48	8.37	6.56	0.96
RM6	24.18	22.61	28.42	6.49	8.36	7.56	0.96

ANGLE T: 4000

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	34.34	31.77	42.84	9.77	15.46	7.71	1.49
RM3	30.86	28.27	36.15	9.29	12.70	4.55	0.96
RM4	27.56	25.38	31.95	8.22	11.16	5.55	0.96
RM5	25.65	23.44	29.67	7.86	10.63	6.55	0.96
RM6	24.20	22.34	28.07	7.33	9.81	7.55	0.96

FORWARD OBSERVER ERROR MODEL NUMBER 2

CHARGE: 6 RANGE: 10000M PER: 34M PED: 5M

PROBABILITY OF ERROR IN MAXIMUM ERROR REGION P:0.25

ANGLE T: 600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	56.97	48.89	80.14	21.89	38.34	9.48	2.94
RM3	35.80	30.72	39.25	14.60	19.81	4.59	1.00
RM4	33.14	28.59	36.35	13.31	17.70	5.59	1.00
RM5	31.04	26.98	34.38	12.42	16.10	6.59	1.00
RM6	28.53	24.75	31.29	11.50	14.86	7.59	1.00

ANGLE T: 800₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	33.45	24.81	31.59	18.48	26.36	11.35	2.15
RM3	34.99	26.32	32.57	19.13	25.15	6.22	1.94
RM4	31.81	24.23	30.05	16.91	22.64	7.56	2.03
RM5	29.63	22.28	27.64	16.20	21.43	8.92	2.14
RM6	27.94	21.01	26.03	15.22	19.87	10.25	2.26

ANGLE T: 1600₥

METHOD	RAD	AMRG	SDRG	AMDF	SDDF	FFERDS	SDRD
C	47.29	25.20	32.62	33.98	47.16	7.30	0.94
RM3	44.96	23.97	29.96	33.11	45.32	4.43	0.70
RM4	42.43	22.41	28.56	30.99	43.10	5.43	0.70
RM5	40.40	21.45	26.90	29.62	41.03	6.43	0.70
RM6	38.21	20.94	26.11	27.59	38.51	7.43	0.70

APPENDIX D: TABULATED RESULTS OF THE X-BAR PROCEDURE

The tabulated results are generated from the computer simulation (described in Section IV) for the precision fire procedure recommended if the forward observer is equipped with the AN/GVS-3 Laser Range Finder. The contents of this Appendix are keyed to the laser system errors in ranging and deviation measurements of the actual bursts. In all instances a uniform distribution for errors is employed. The specific results may be found on the following pages:

The no error results	pages 135 to 139
Range error=±10 meters Deflection error=±2 mils	pages 140 to 144
Range error=±20 meters Deflection error=±4 mils	pages 145 to 149
Range error=±40 meters Deflection error=±8 mils	pages 150 to 154

The abbreviations used in the tables are as follows:

RAD -The average radial miss distance.

AMRG-The average absolute miss distance in range

AMDF-The average absolute miss distance in deviation

SDRG-The standard deviation of the range miss component

SDDF-The standard deviation of the deflection miss component.

note: the numbers appearing under the ROUNDS column correspond to the actual number of rounds lased to attain estimate of true target center location.

LASER RANGE FINDER DATA

CHARGE: 5GB RANGE: 2000M PER: 7M PED: 1M

RANGE ERROR: 0M DEVIATION ERROR: 0m̸

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10m̸	3.99	3.80	5.02	1.03	1.27
5	"	3.61	3.44	4.54	0.99	1.23
6	"	3.44	3.27	4.28	0.99	1.22
4	200m̸	4.17	3.97	5.19	1.03	1.28
5	"	3.80	3.59	4.67	1.00	1.24
6	"	3.58	3.38	4.41	0.99	1.23
4	400m̸	4.15	3.94	5.19	1.01	1.27
5	"	3.66	3.44	4.57	0.99	1.23
6	"	3.41	3.21	4.27	0.97	1.21
4	600m̸	4.39	4.18	5.46	1.01	1.25
5	"	3.90	3.69	4.86	1.00	1.23
6	"	3.56	3.36	4.44	0.99	1.23
4	800m̸	4.30	4.07	5.35	0.95	1.19
5	"	3.95	3.73	4.89	0.94	1.17
6	"	3.61	3.39	4.44	0.94	1.17
4	1600m̸	4.20	3.96	5.18	0.97	1.20
5	"	3.76	3.53	4.67	0.95	1.18
6	"	3.58	3.34	4.44	0.95	1.18

LASER RANGE FINDER DATA

CHARGE: 5GB   RANGE: 6000M   PER: 13M   PED: 3M

RANGE ERROR: 0M   DEVIATION ERROR: 0m̸

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10m̸	8.34	7.94	9.81	2.64	3.30
5	"	7.54	7.06	8.91	2.62	3.28
6	"	6.80	6.23	7.91	2.62	3.28
4	200m̸	8.20	7.72	9.59	2.73	3.38
5	"	7.65	7.19	8.80	2.70	3.34
6	"	7.14	6.63	8.08	2.70	3.34
4	400m̸	8.32	7.85	9.84	2.70	3.36
5	"	7.70	7.24	8.94	2.68	3.34
6	"	7.14	6.63	8.09	2.68	3.34
4	600m̸	8.44	8.13	10.11	2.50	3.13
5	"	7.67	7.32	9.07	2.48	3.10
6	"	6.97	6.54	8.17	2.47	3.08
4	800m̸	8.27	7.84	9.76	2.65	3.31
5	"	7.32	6.90	8.48	2.62	3.26
6	"	6.78	6.27	7.77	2.62	3.26
4	1600m̸	8.36	7.91	9.90	2.69	3.32
5	"	7.73	7.29	8.93	2.67	3.30
6	"	7.12	6.62	8.09	2.67	3.29

LASER RANGE FINDER DATA

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 3M

RANGE ERROR: 0M DEVIATION ERROR: 0₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	12.32	12.20	15.15	2.52	3.13
5	"	11.18	11.03	13.76	2.49	3.09
6	"	10.41	10.21	12.51	2.47	3.07
4	200₥	12.09	11.90	14.78	2.55	3.15
5	"	10.77	10.51	13.16	2.51	3.09
6	"	9.70	9.44	11.83	2.49	3.07
4	400₥	11.65	11.50	14.45	2.53	3.15
5	"	10.69	10.47	13.34	2.48	3.10
6	"	10.02	9.80	12.35	2.46	3.08
4	600₥	11.87	11.72	14.68	2.49	3.10
5	"	10.67	10.46	13.25	2.45	3.05
6	"	9.95	9.75	12.24	2.42	3.01
4	800₥	11.74	11.65	14.67	2.39	2.98
5	"	10.85	10.69	13.41	2.36	2.94
6	"	9.97	9.73	12.33	2.36	2.93
4	1600₥	11.78	11.66	14.61	2.43	3.05
5	"	10.81	10.64	13.31	2.42	3.03
6	"	9.95	9.72	12.38	2.41	3.02

LASER RANGE FINDER DATA

CHARGE: 6 RANGE: 8000M PER: 27M PED: 4M

RANGE ERROR: 0M DEVIATION ERROR: 0m̸

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10m̸	16.67	16.31	20.54	3.42	4.26
5	"	14.71	14.32	18.01	3.37	4.18
6	"	13.37	12.88	16.30	3.37	4.18
4	200m̸	15.68	15.23	19.00	3.47	4.31
5	"	14.02	13.55	16.93	3.44	4.27
6	"	12.98	12.46	15.66	3.44	4.27
4	400m̸	16.60	16.14	20.28	3.51	4.37
5	"	14.83	14.32	17.92	3.47	4.33
6	"	13.99	13.50	16.56	3.47	4.33
4	600m̸	16.75	16.47	20.44	3.24	4.01
5	"	15.07	14.78	18.24	3.20	3.94
6	"	13.61	13.19	16.62	3.20	3.94
4	800m̸	16.99	16.63	20.86	3.43	4.27
5	"	15.42	15.02	18.74	3.38	4.22
6	"	13.88	13.43	16.68	3.37	4.20
4	1600m̸	16.45	1600	20.45	3.43	4.34
5	"	14.90	14.45	18.17	3.37	4.24
6	"	13.27	12.73	15.98	3.37	4.24

LASER RANGE FINDER DATA

CHARGE: 6   RANGE: 10000M   PER: 34M   PED: 5M

RANGE ERROR: 0M   DEVIATION ERROR: 0₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	20.16	19.51	24.53	4.25	5.21
5	"	18.10	17.47	21.65	4.23	5.18
6	"	16.57	15.86	19.74	4.23	5.18
4	200₥	19.75	19.04	24.20	4.27	5.37
5	"	18.50	17.85	22.23	4.21	5.28
6	"	16.88	16.14	20.08	4.18	5.24
4	400₥	20.09	19.41	24.33	4.28	5.38
5	"	18.30	17.70	21.96	4.26	5.35
6	"	17.19	16.51	20.30	4.26	5.35
4	600₥	20.90	20.33	25.35	4.32	5.43
5	"	18.79	18.13	22.61	4.28	5.36
6	"	17.22	16.47	20.67	4.27	5.35
4	800₥	20.22	19.59	24.65	4.26	5.29
5	"	18.73	18.09	22.51	4.24	5.27
6	"	17.14	16.41	20.31	4.24	5.27
4	1600₥	20.95	20.30	25.35	4.20	5.28
5	"	18.34	17.70	22.22	4.15	5.22
6	"	17.31	16.66	20.64	4.15	5.22

LASER RANGE FINDER DATA

CHARGE: 5GB   RANGE: 200M   PER: 7M   PED: 1M

RANGE ERROR: 10M   DEVIATION ERROR: 2m̸

ROUNDS	ANGLE	RAD	AMRG	SDRG	AMDF	SDDF
4	10m̸	4.92	4.66	5.80	1.57	1.93
5	"	4.15	3.99	5.02	1.48	1.84
6	"	3.96	3.71	4.66	1.37	1.71
4	200m̸	5.17	4.92	6.11	1.66	2.05
5	"	4.68	4.42	5.47	1.56	1.93
6	"	4.29	4.03	4.99	1.47	1.81
4	400m̸	5.12	4.79	5.97	1.78	2.19
5	"	4.53	4.24	5.32	1.60	2.00
6	"	4.18	3.90	4.81	1.50	1.83
4	600m̸	4.83	4.48	5.74	1.84	2.23
5	"	4.45	4.11	5.20	1.69	2.08
6	"	4.15	3.82	4.77	1.60	1.98
4	800m̸	4.84	4.39	5.48	2.13	2.61
5	"	4.29	3.85	4.82	1.91	2.35
6	"	3.92	3.49	4.36	1.79	2.23
4	1600m̸	4.83	4.14	5.24	2.50	3.07
5	"	4.36	3.82	4.78	2.27	2.77
6	"	4.12	3.54	4.42	2.12	2.60

LASER RANGE FINDER DATA

CHARGE: 5GB   RANGE: 6000M   PER: 13M   PED: 3M

RANGE ERROR: 10M   DEVIATION ERROR: 2m̸

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10m̸	8.70	8.20	10.40	2.81	3.50
5	"	7.74	7.21	9.15	2.77	3.46
6	"	7.21	6.64	8.42	2.77	3.46
4	200m̸	8.59	8.13	10.06	2.74	3.42
5	"	7.53	6.99	8.85	2.70	3.35
6	"	7.05	6.50	8.23	2.68	3.32
4	400m̸	8.58	8.10	10.09	2.88	3.62
5	"	7.74	7.26	9.00	2.78	3.48
6	"	6.87	6.29	7.92	2.77	3.47
4	600m̸	8.39	7.71	9.48	3.13	3.95
5	"	7.71	7.02	8.71	3.03	3.80
6	"	7.13	6.36	7.98	3.01	3.77
4	800m̸	8.39	7.68	9.79	3.17	3.93
5	"	7.67	6.95	8.88	3.05	3.75
6	"	7.17	6.36	8.17	3.00	3.69
4	1600m̸	8.30	7.39	9.45	3.46	4.37
5	"	7.37	6.52	8.26	3.21	4.06
6	"	7.06	6.20	7.89	3.17	3.99

LASER RANGE FINDER DATA

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 3M

RANGE ERROR: 10M DEVIATION ERROR: 2₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	11.98	11.68	14.73	2.72	3.42
5	"	11.07	10.75	13.39	2.69	3.35
6	"	9.98	9.74	12.05	2.64	3.29
4	200₥	12.08	11.84	14.84	2.66	3.33
5	"	10.92	10.65	13.53	2.59	3.24
6	"	10.17	9.96	12.51	2.53	3.16
4	400₥	12.09	11.76	14.86	2.88	3.59
5	"	10.71	10.39	12.96	2.79	3.49
6	"	10.01	9.67	12.25	2.72	3.39
4	600₥	12.09	11.74	14.70	2.99	3.73
5	"	11.11	10.81	13.45	2.85	3.53
6	"	10.49	10.17	12.62	2.79	3.46
4	800₥	12.47	12.05	15.14	3.10	3.88
5	"	11.23	10.81	13.51	2.97	3.71
6	"	10.17	9.76	12.14	2.93	3.65
4	1600₥	12.73	12.17	15.27	3.33	4.22
5	"	11.59	11.04	13.85	3.21	4.05
6	"	10.71	10.21	12.70	3.11	3.90

LASER RANGE FINDER DATA

CHARGE: 6 RANGE: 8000M PER: 27M PED: 4M

RANGE ERROR: 10M DEVIATION ERROR: 2₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	15.94	15.45	19.49	3.51	4.39
5	"	14.68	14.23	17.45	3.48	4.33
6	"	13.25	12.73	15.77	3.47	4.30
4	200₥	15.95	15.45	19.14	3.73	4.65
5	"	14.23	13.61	16.98	3.66	4.57
6	"	13.04	12.30	15.48	3.65	4.56
4	400₥	16.03	15.46	19.41	3.66	4.55
5	"	14.77	14.24	17.76	3.58	4.44
6	"	13.63	13.12	16.16	3.54	4.41
4	600₥	16.46	15.77	20.20	3.91	4.94
5	"	14.69	13.98	17.83	3.78	4.81
6	"	13.53	12.81	16.25	3.73	4.76
4	800₥	17.15	16.56	20.72	3.87	4.90
5	"	15.51	14.91	18.60	3.72	4.71
6	"	14.16	13.55	16.97	3.68	4.62
4	1600₥	16.26	15.55	19.40	4.11	5.13
5	"	14.51	13.78	17.32	3.93	4.92
6	"	13.28	12.52	15.58	3.88	4.87

LASER RANGE FINDER DATA

CHARGE: 6   RANGE: 10000M   PER: 34M   PED: 5M

RANGE ERROR: 10M   DEVIATION ERROR: 2₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	20.70	20.00	25.38	4.49	5.65
5	"	18.85	18.06	22.65	4.40	5.53
6	"	17.68	16.83	21.01	4.38	5.51
4	200₥	22.13	21.35	27.14	4.55	5.67
5	"	20.05	19.32	24.40	4.48	5.59
6	"	18.10	17.21	21.80	4.46	5.57
4	400₥	20.46	19.62	25.05	4.68	5.88
5	"	18.69	17.86	22.45	4.55	5.71
6	"	17.58	16.65	20.80	4.53	5.69
4	600₥	19.89	19.06	24.24	4.61	5.85
5	"	18.42	17.66	22.11	4.55	5.77
6	"	17.00	16.07	20.12	4.53	5.75
4	800₥	21.10	20.46	25.70	4.33	5.51
5	"	18.69	17.98	22.62	4.30	5.43
6	"	17.15	16.42	20.37	4.27	5.39
4	1600₥	20.50	19.58	24.69	4.82	6.02
5	"	18.32	17.51	21.81	4.62	5.76
6	"	16.65	15.78	19.51	4.59	5.73

LASER RANGE FINDER DATA

CHARGE: 5GB   RANGE: 2000M   PER: 7M   PED: 1M

RANGE ERROR: 20M   DEVIATION ERROR: 4₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	6.41	6.03	7.71	2.42	3.00
5	"	5.58	5.24	6.64	2.21	2.72
6	"	5.07	4.74	6.03	2.12	2.60
4	200₥	6.37	5.78	7.19	2.70	3.32
5	"	5.53	5.08	6.36	2.39	2.98
6	"	4.98	4.57	5.74	2.24	2.78
4	400₥	6.15	5.49	6.87	2.77	3.47
5	"	5.59	5.07	6.33	2.50	3.13
6	"	5.07	4.65	5.80	2.27	2.86
4	600₥	6.55	5.74	7.09	3.22	3.95
5	"	5.85	5.16	6.36	2.88	3.56
6	"	5.37	4.74	5.83	2.72	3.38
4	800₥	6.72	5.58	7.00	3.62	4.56
5	"	5.97	4.96	6.26	3.23	4.12
6	"	5.35	4.43	5.61	2.98	3.80
4	1600₥	6.93	4.98	6.21	4.52	5.66
5	"	6.04	4.37	5.46	3.84	5.46
6	"	5.40	3.99	4.97	3.57	4.50

LASER RANGE FINDER DATA

CHARGE: 5GB RANGE: 6000M PER: 13M PED: 3M

RANGE ERROR: 20M DEVIATION ERROR: 4₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	9.99	9.22	11.49	3.51	4.25
5	"	8.92	8.22	10.18	3.26	3.97
6	"	8.22	7.45	9.39	3.19	3.89
4	200₥	9.30	8.44	10.57	3.44	4.30
5	"	8.38	7.53	9.53	3.27	4.09
6	"	7.61	6.76	8.57	3.19	4.01
4	400₥	9.39	8.31	10,40	3.90	4.85
5	"	8.64	7.64	9.47	3.46	4.53
6	"	7.94	6.95	8.66	3.53	4.40
4	600₥	9.66	8.41	10.60	4.06	5.08
5	"	8.74	7.73	9.52	3.71	4.72
6	"	7.88	6.85	8.59	3.55	4.51
4	800₥	10.30	9.01	11.28	4.27	5.41
5	"	9.18	8.08	9.90	3.95	5.01
6	"	8.35	7.27	8.98	3.76	4.74
4	1600₥	10.07	8.22	10.25	5.10	6.34
5	"	9.05	7.48	9.10	4.57	5.67
6	"	8.15	6.66	8.25	4.25	5.27

LASER RANGE FINDER DATA

CHARGE: 5WB RANGE: 5500M PER: 20M PED: 13M

RANGE ERROR: 20M DEVIATION ERROR: 4₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	13.55	13.01	16.13	3.58	4.43
5	"	11.83	11.31	14.07	3.32	4.13
6	"	10.79	10.28	12.91	3.14	3.91
4	200₥	13.35	12.75	15.80	3.63	4.50
5	"	12.03	11.49	14.21	3.38	4.19
6	"	10.71	10.20	12.81	3.20	3.96
4	400₥	12.80	12.16	15.34	3.60	4.46
5	"	11.40	10.79	13.54	3.40	4.25
6	"	10.81	10.25	12.77	3.25	4.05
4	600₥	12.75	11.87	15.07	3.90	4.84
5	"	11.48	10.65	13.47	3.70	4.64
6	"	10.23	9.52	11.92	3.46	4.30
4	800₥	13.20	12.16	15.07	4.38	5.48
5	"	11.65	10.59	13.27	4.05	5.07
6	"	10.44	9.46	12.08	3.82	4.79
4	1600₥	13.23	11.72	14.57	5.18	6.41
5	"	12.17	11.00	13.45	4.53	5.63
6	"	10.94	9.85	12.30	4.19	5.19

LASER RANGE FINDER DATA

CHARGE: 6   RANGE: 8000M   PER: 27M   PED: 4M

RANGE ERROR: 20M   DEVIATION ERROR: 4₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	17.29	16.70	20.78	3.96	4.88
5	"	15.91	15.33	19.08	3.80	4.68
6	"	14.32	13.66	17.11	3.80	4.69
4	200₥	16.69	15.91	19.87	4.25	5.25
5	"	14.90	14.14	17.41	4.11	5.09
6	"	13.65	12.81	15.90	4.00	4.92
4	400₥	17.45	16.72	20.84	4.31	5.39
5	"	15.95	15.27	10.03	4.07	5.09
6	"	14.45	13.75	17.03	3.93	4.91
4	600₥	16.99	16.02	20.24	4.62	5.72
5	"	15.73	14.81	18.57	4.43	5.51
6	"	14.17	13.22	16.57	4.26	5.30
4	800₥	17.51	16.46	20.38	4.78	5.99
5	"	15.42	14.33	17.94	4.65	5.76
6	"	13.98	12.92	16.12	4.43	5.51
4	1600₥	17.31	16.04	19.86	5.25	6.63
5	"	15.35	14.15	17.64	4.81	6.02
6	"	14.10	12.94	16.04	4.61	5.75

LASER RANGE FINDER DATA

CHARGE: 6   RANGE: 10000M   PER: 34M   PED: 5M

RANGE ERROR: 20M   DEVIATION ERROR: 4m̸

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10m̸	21.55	20.76	26.16	4.71	5.93
5	"	20.15	19.32	24.24	4.67	5.88
6	"	18.58	17.61	21.22	4.62	5.80
4	200m̸	21.42	20.48	25.69	5.09	6.38
5	"	19.67	18.74	23.38	4.89	6.12
6	"	17.88	16.89	21.06	4.84	6.07
4	400m̸	22.21	21.19	26.33	5.14	6.40
5	"	19.98	19.00	23.59	5.00	6.23
6	"	18.28	17.20	21.59	4.98	6.20
4	600m̸	20.70	19.58	24.59	5.33	6.64
5	"	18.62	17.41	22.06	5.17	6.44
6	"	17.46	16.24	20.42	5.12	6.38
4	800m̸	20.38	19.18	24.09	5.48	6.93
5	"	18.65	17.58	21.65	5.14	6.45
6	"	17.16	16.06	19.73	5.00	6.34
4	1600m̸	21.10	19.43	24.58	6.41	7.97
5	"	19.06	17.46	21.97	6.05	7.59
6	"	17.73	16.12	20.28	5.75	7.23

LASER RANGE FINDER DATA

CHARGE: 5GB RANGE: 2000M PER: 7M PED: 1M

RANGE ERROR: 40M DEVIATION ERROR: 8₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	10.86	9.36	11.93	4.69	5.85
5	"	9.57	8.35	10.55	4.18	5.24
6	"	8.56	7.50	9.48	3.74	4.67
4	200₥	11.41	9.81	12.22	5.06	6.25
5	"	9.98	8.71	10.98	4.31	5.42
6	"	8.99	7.81	9.85	4.01	5.06
4	400₥	11.20	9.26	11.77	5.57	6.90
5	"	9.93	8.30	10.51	4.88	6.12
6	"	8.95	7.61	9.54	4.37	5.50
4	600₥	11.72	8.95	11.37	6.69	8.45
5	"	10.42	8.03	10.10	5.95	7.61
6	"	9.17	7.16	9.08	5.18	6.68
4	800₥	11.08	8.01	10.04	7.02	8.85
5	"	9.70	7.03	8.75	6.26	7.96
6	"	8.78	6.34	7.99	5.70	7.26
4	1600₥	11.09	5.97	7.37	8.65	10.99
5	"	9.80	5.26	6.55	7.70	9.81
6	"	8.83	4.78	5.89	7.01	8.92

LASER RANGE FINDER DATA

CHARGE: 5GB RANGE: 6000M PER: 13M PED: 3M

RANGE ERROR: 40M DEVIATION ERROR: 8₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	13.71	12.28	15.24	5.20	6.40
5	"	12.30	11.01	13.67	4.73	5.90
6	"	11.01	9.79	12.29	4.35	5.43
4	200₥	12.96	11.33	14.29	5.34	6.77
5	"	11.65	10.20	12.75	4.83	6.15
6	"	10.72	9.42	11.82	4.44	5.62
4	400₥	13.07	10.99	13.87	6.04	7.58
5	"	11.57	9.91	12.40	5.24	6.63
6	"	10.47	8.95	11.10	4.78	6.07
4	600₥	14.24	11.62	14.38	7.00	8.78
5	"	12.72	10.41	12.93	6.20	7.83
6	"	11.67	9.58	11.99	5.68	7.18
4	800₥	13.23	10.04	12.78	7.45	9.42
5	"	11.55	8.77	11.12	6.56	8.33
6	"	10.60	8.05	10.24	6.12	7.80
4	1600₥	13.78	8.97	11.26	9.10	11.50
5	"	12.34	8.35	10.30	7.95	10.16
6	"	11.17	7.56	9.44	7.28	9.15

LASER RANGE FINDER DATA

CHARGE: 5WB   RANGE: 5500M   PER: 20M   PED: 3M

RANGE ERROR: 40M   DEVIATION ERROR: 8₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	16.26	15.07	18.74	5.06	6.21
5	"	14.45	13.40	16.91	4.60	5.68
6	"	12.90	11.91	14.97	4.19	5.21
4	200₥	16.69	15.35	19.08	5.47	6.77
5	"	14.64	13.46	16.79	4.86	6.03
6	"	13.35	12.21	15.40	4.61	5.66
4	400₥	16.58	14.66	18.61	6.16	7.74
5	"	14.45	12.99	16.45	5.43	6.71
6	"	13.04	11.58	14.58	5.10	6.33
4	600₥	16.79	14.54	18.12	6.96	8.62
5	"	14.65	12.58	15.79	6.17	7.71
6	"	13.52	11.72	14.59	5.62	6.98
4	800₥	17.19	14.07	17.73	8.26	10.10
5	"	15.03	12.35	15.59	7.27	9.00
6	"	13.56	11.10	14.07	6.67	8.32
4	1600₥	16.57	12.45	15.56	9.30	11.59
5	"	14.85	11.22	14.08	8.10	10.17
6	"	13.84	10.38	12.93	7.75	9.67

LASER RANGE FINDER DATA

CHARGE: 6   RANGE: 8000M   PER: 27M   PED: 4M

RANGE ERROR: 40M   DEVIATION ERROR: 8₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	19.82	18.39	23.11	5.76	7.14
5	"	17.97	16.70	20.88	5.34	6.62
6	"	16.19	14.98	18.69	5.11	6.34
4	200₥	18.75	17.24	22.01	5.89	7.27
5	"	17.42	16.00	20.29	5.59	6.88
6	"	16.25	14.88	18.97	5.27	6.50
4	400₥	19.43	17.78	22.29	6.20	7.74
5	"	17.02	15.45	19.23	5.82	7.21
6	"	15.81	14.43	17.82	5.40	6.69
4	600₥	19.61	17.40	21.85	7.17	8.95
5	"	17.61	15.64	19.39	6.58	8.22
6	"	16.48	14.62	18.11	6.20	7.72
4	800₥	19.91	17.19	21.33	8.24	10.02
5	"	17.27	14.77	18.59	7.13	8.98
6	"	15.80	13.47	16.88	6.62	8.39
4	1600₥	20.80	16.79	20.98	9.81	12.25
5	"	18.80	15.16	18.84	9.18	11.30
6	"	16.80	13.44	17.03	8.22	10.28

LASER RANGE FINDER DATA

CHARGE: 6   RANGE: 10000M   PER: 34M   PED: 5M

RANGE ERROR: 40M   DEVIATION ERROR: 8₥

ROUNDS	ANGLE T	RAD	AMRG	SDRG	AMDF	SDDF
4	10₥	22.75	21.19	26.90	6.35	7.93
5	"	20.70	19.31	24.14	5.89	7.39
6	"	19.34	17.99	22.49	5.66	7.07
4	200₥	23.33	21.66	27.10	6.64	8.16
5	"	20.78	19.20	24.37	6.12	7.56
6	"	19.39	17.85	22.71	5.88	7.30
4	400₥	23.26	21.08	26.50	7.44	9.34
5	"	20.88	19.00	23.91	6.74	8.45
6	"	19.14	17.38	22.01	6.24	7.82
4	600₥	24.25	22.14	27.50	7.87	9.72
5	"	21.52	19.49	24.41	7.06	8.85
6	"	19.88	18.04	22.52	6.56	8.32
4	800₥	22.73	20.21	25.25	8.07	9.93
5	"	20.89	18.85	23.16	7.31	9.18
6	"	19.38	17.31	21.71	6.97	8.80
4	1600₥	23.25	19.60	24.70	9.85	12.32
5	"	21.09	17.84	22.41	9.04	11.07
6	"	19.67	16.61	20.67	8.47	10.36

APPENDIX E FM 6-40 AND ROBBINS-MONRO ONE ROUND PRECISION FIRE SIMULATION PROGRAM LISTING(SIMPLE MODEL)

THE PURPOSE OF THIS APPENDIX IS TO PROVIDE THE COMPUTER PROGRAM LISTINGS OF THE FM 6-40 AND ROBBINS-MONRO ONE ROUND PRECISION FIRE TECHNIQUES DESCRIBED IN SECTION IV.THE ALPHABETICAL LISTING AND DESCRIPTION OF VARIABLE NAMES COMMON TO BOTH PROGRAMS IS AS FOLLOWS:

ABSAV-	AVERAGE ABSOLUTE REGISTRATION RANGE ERROR
ADJCI-	REGISTRATION RANGE ERROR
AV-	AVERAGE REGISTRATION RANGE ERROR
AVRDS-	AVERAGE NUMBER OF FIRE FOR EFFECT ROUNDS
CENTER-	THE MEAN OF THE FORK BRACKET
COUNT-	OBSERVER SENSING OF OVER AND SHORT ROUNDS
DIFF-	THE DIFFERENCE BETWEEN OVER AND SHORT SPOTS
IN-	POSITIVE SPOT INDEX
IX-	RANDOM NUMBER SEED
J-	MISSION COUNTER
KB-	RANDOM NUMBER INDEX
M-	ADJUSTMENT PHASE ROUND INDEX
N-	FIRE FOR EFFECT ROUND INDEX
NF-	POSITIVE RANGE SPOT ROUND INDEX
NITER-	SPECIFIES THE NUMBER OF ROUNDS TO FIRE FOR EACH PRECISION MISSION
NO-	INDEX FOR NUMBER OF MISSIONS TO BE SIMULATED
NROUND-	SUM OF ALL ROUNDS FIRED IN THE FIRE FOR EFFECT PHASE
NZ-	POSITIVE RANGE SPOT INDEX
OR1-	OVER SPOT CORRESPONDING TO RANGE1
OR2-	OVER SPOT CORRESPONDING TO RANGE2
OTHER-	APPROPRIATE END OF THE FIRE FOR EFFECT FORK BRACKET AT WHICH THE LAST TWO ROUNDS WERE FIRED
OVER-	OVER SPOT
PE-	FOUR RANGE PROBABLE ERRORS(FORK)
PER-	PROBABLE ERROR IN RANGE VALUE
PERR-	PROBABILITY OF OBSERVER SENSING ERROR

RABS-	SUM OF REGISTRATION ABSOLUTE RANGE ERRORS
RANG-	SUM OF REGISTRATION RANGE ERRORS
RANGA-	SUM OF REGISTRATION ABSOLUTE RANGE ERRORS
RANGE-	THE DIFFERENCE BETWEEN THE MEAN OF THE BALLISTIC DISTRIBUTION AND THE TRUE TARGET CENTER
RANGE1-	THE BALLISTIC MEAN LOCATION OF INITIAL END OF FORK BRACKET
RANGE2-	THE BALLISTIC MEAN LOCATION OF TERMINAL END OF FORK BRACKET
RANGSQ-	SUM OF SQUARES OF REGISTRATION RANGE ERRORS
RG-	THE DIFFERENCE BETWEEN BURST IMPACT AND TRUE TARGET CENTER
RMIS-	SUM OF REGISTRATION RANGE ERROR
RNG-	SEE RANGE
RSQ-	SUM OF SQUARES OF REGISTRATION RANGE ERRORS
RUN-	NORMAL N(0,1) RANDOM NUMBER
SD-	STANDARD DEVIATION OF AVERAGE REGISTRATION RANGE ERROR
SDRD-	STANDARD DEVIATION OF AVERAGE FIRE FOR EFFECT ROUNDS
SENS-	OBSERVER SENSING OF OVER AND SHORT IMPACTS
SENSE-	OBSERVER SENSING OF OVER AND SHORT ROUNDS
SH1-	SHORT SPOT CORRESPONDING TO RANGE1
SH2-	SHORT SPOT CORRESPONDING TO RANGE2
SHIFT-	RANGE SHIFT FOR THE ADJUSTMENT PHASE
SHORT-	SHORT SPOT
SPOT-	OBSERVER SENSING OF OVER AND SHORT IMPACTS
SQN-	SUM OF SQUARES OF ALL ROUNDS FIRED IN THE FIRE FOR EFFECT PHASE
TEST-	SPECIFIES THE LAST RANGE SHIFT TO BE USED IN THE ADJUSTMENT PHASE
TEST1-	THE VALUE OF THE RECURSIVE CONSTANT FOR THE ROBBINS-MONRO PROCEDURE
W-	RANGE CORRECTION AFTER EACH FIRE FOR EFFECT ROUND OF ROBBINS-MONRO PROCEDURE

ZZ- SPECIFIES NUMBER OF USABLE ROUND FOR ROBBINS-MONRO PROCEDURE

```
C     FM 6-40 PRECISION FIRE PROGRAM LISTING (SIMPLE MODEL)
C
      DIMENSION SPOT(50),NROUND(6),ADJCI(6),SGN(6),RMIS(6),R
     1ABS(6),RSQ(6),AVRDS(6),SDRD(6),AV(6),ABSAV(6),SD(6),SE
     1NS(50)
C
C     UNIFORM U(0,1) RANDOM NUMBER GENERATOR IS INITIALIZED
C
      CALL OVFLOW
      IX=327328403
      KB=1
C
C     VECTOR ARRAYS ARE ZEROED OUT
C
      DO 70 I=1,6
      AVRDS(I)=0.0
      SDRD(I)=0.0
      ABSAV(I)=0.0
      AV(I)=0.0
      NROUND(I)=0
      SGN(I)=0.0
      RMIS(I)=0.0
      RABS(I)=0.0
      RSQ(I)=0.0
   70 SD(I)=0.0
C
C     PER VALUE TO BE INVESTIGATED IS SET
C
      PER=20.0
      WRITE(6,8000)PER
C
C     NUMBER OF REPLICATIONS TO RUN IS SPECIFIED
C
      NC=1000
      J=0
    1 J=J+1
      PE=PER*4.0
      DO 76 I=1,6
      ADJCI(I)=0.0
   76 CONTINUE
      DO 2 I=1,50
      SENS(I)=0.0
    2 SPOT(I)=0.0
C
C     COUNTERS ARE ZEROED OUT
C
      SHORT=0.0
      OVER=0.0
      M=0
      N=0
      NF=0
      NZ=0
      CALL RANDOM(IX,RAN,KB)
C
C     THE INITIAL AIMPOINT LOCATION RELATIVE TO THE TARGET
C     IS ESTABLISHED. THE INITIAL AIMPOINTS WILL BE UNIFORM-
C     LY DISTRIBUTED +200, -200 METERS OF THE TRUE TARGET
C     CENTER
C
      RANGE=RAN*200.0
      CALL RANDOM(IX,RAN,KB)
      IF(RAN.LT..5)RANGE=-RANGE
C
C     THE INITIAL RANGE SHIFT FOR ALL MISSIONS IS 200
C     METERS
C
      SHIFT=200.0
      TEST=50.0
  310 M=M+1
      RUN=GRN(0)
C
C     ACTUAL IMPACT LOCATION IS COMPUTED
```

```
C
      RG=RUN*PER/.6745+RANGE
C
C     OBSERVER DETERMINES IF IMPACT IS OVER OR SHORT OF THE
C     TARGET
C
      SENS(M)=RG
      IF(M.GT.1)GO TO 313
  320 IF(SENS(M))311,311,312
  311 RANGE=RANGE+SHIFT
      GO TO 310
  312 RANGE=RANGE-SHIFT
      GO TO 310
C
C     OBSERVER DETERMINES IF A RANGE BRACKET HAS BEEN ESTAB-
C     LISHED
C
  313 IF(SENS(M).GT.0.0.AND.SENS(M-1).GT.0.0.OR.SENS(M).LT.0
     1.0.AND.SENS(M-1).LT.0.0)GO TO 320
C
C     THE RANGE BRACKET IS HALVED
C
      SHIFT=SHIFT*0.5
      IF(SENS(M))314,314,315
  314 RANGE=RANGE+SHIFT
      GO TO 316
  315 RANGE=RANGE-SHIFT
C
C     THE DETERMINATION TO ENTER THE FIRE FOR EFFECT PHASE
C     IS MADE
C
  316 IF(SHIFT.GT.TEST)GO TO 310
    3 N=N+1
      RUN=GRN(0)
      RG=RUN*PER/.6745+RANGE
   60 SPOT(N)=RG
      IF(SPOT(N))4,4,5
C
C     ONE END OF THE FORK BRACKET IS ESTABLISHED
C
    4 RANGE1=RANGE
      SH1=1.0
      OR1=0.0
      RANGE=RANGE+PE
      GO TO 6
    5 RANGE1=RANGE
      OR1=1.0
      SH1=0.0
      RANGE=RANGE-PE
    6 N=N+1
      RUN=GRN(0)
      RG=RUN*PER/.6745+RANGE
      SPOT(N)=RG
C
C     A DETERMINATION IS MADE TO SEE IF A FORK BRACKET HAS
C     BEEN ACHIEVED
C
      IF(SPOT(N).GT.0.0.AND.SPOT(N-1).GT.0.0.OR.SPOT(N).LT.0
     1.0.AND.SPOT(N-1).LT.0.0)GO TO 60
      IF(SPOT(N))7,7,8
    7 RANGE2=RANGE
      SH2=1.0
      OR2=0.0
C
C     THE FORK BRACKET IS SPLIT
C
      RANGE=RANGE+PE/2.0
      GO TO 9
    8 RANGE2=RANGE
      OR2=1.0
      SH2=0.0
      RANGE=RANGE-PE/2.0
```

```
    9 CENTER=RANGE
C
C     THREE ROUNDS ARE FIRED AT THE MEAN OF THE HALF FORK
C     BRACKET
C
   10 N=N+1
      NF=NF+1
      RUN=GRN(0)
      RG=RUN*PER/.6745+RANGE
      SPOT(N)=RG
      IF(SPOT(N))11,11,12
   11 SHORT=SHORT+1.0
      GO TO 13
   12 OVER=OVER+1.0
   13 IF(NF-3)10,14,14
   14 IF((OVER-SHORT).GT.0.0)GO TO 15
      RANGE=RANGE+PE/2.0
      GO TO 16
   15 RANGE=RANGE-PE/2.0
   16 OTHER=RANGE
C
C     THE APPROPRIATE FORK BRACKET TO FIRE THE LAST GROUP OF
C     ROUNDS IS MADE; 3.5 IS USED AS A BUFFER SAFETY AGAINST
C     COMPUTER ROUND OFF ERRORS TO ENSURE APPROPRIATE END OF
C     THE FORK BRACKET IS USED
C
      IF(ABS(OTHER-RANGE1).LT.3.5)GO TO 17
      OVER=OVER+OR2
      SHORT=SHORT+SH2
      GO TO 18
   17 OVER=OVER+OR1
      SHORT=SHORT+SH1
C
C     TWO ROUNDS ARE FIRED AT THE APPROPRIATE END OF THE
C     FORK BRACKET TO COMPLETE THE REGISTRATION
C
   18 N=N+1
      NZ=NZ+1
      RUN=GRN(0)
      RG=RUN*PER/.6745+RANGE
      SPOT(N)=RG
      IF(SPOT(N))19,19,20
   19 SHORT=SHORT+1.0
      GO TO 21
   20 OVER=OVER+1.0
   21 IF(NZ-2)18,22,22
   22 DIFF=SHORT-OVER
      IN=1
      RNG=(CENTER+OTHER)/2.0
C
C     THE REGISTRATION ERROR IS COMPUTED AND THE DATA FOR
C     STATISTICAL ANALYSIS OF THE REGISTRATION IS COLLATED
C
      ADJCI(IN)=RNG+(DIFF*PE/12.0)
      NROUND(IN)=NROUND(IN)+N
      SQN(IN)=SQN(IN)+N*N
      RMIS(IN)=RMIS(IN)+ADJCI(IN)
      RABS(IN)=RABS(IN)+ABS(ADJCI(IN))
      RSQ(IN)=RSQ(IN)+(ADJCI(IN))*(ADJCI(IN))
   30 RANGE=ADJCI(IN)
      IN=IN+1
      OVER=0.0
      SHORT=0.0
      NZ=0
C
C     THE PROGRAM COMPUTATIONS FOLLOWING INVESTIGATE RANGE
C     ACCURACY OF THE SUCCEEDING FIVE SIX ROUND GROUPS WHICH
C     SIMULATE FM-6-40 DESTRUCTION PROCEDURE.
C
   31 N=N+1
      NZ=NZ+1
      RUN=GRN(0)
```

```
      RG=RUN*PER/.6745+RANGE
      SPOT(N)=RG
      IF(SPOT(N))32,32,33
   32 SHORT=SHORT+1.0
      GO TO 34
   33 OVER=OVER+1.0
   34 IF(NZ-6)31,35,35
   35 DIFF=SHORT-OVER
      ADJCI(IN)=RANGE+(DIFF*PE/12.0)*(1.0/FLOAT(IN))
      NROUND(IN)=NROUND(IN)+N
      SQN(IN)=SQN(IN)+N*N
      RMIS(IN)=RMIS(IN)+ADJCI(IN)
      RABS(IN)=RABS(IN)+ABS(ADJCI(IN))
      RSQ(IN)=RSQ(IN)+(ADJCI(IN))*(ADJCI(IN))
      IF(IN-6)30,36,36
   36 IF(J-NO)1,23,23
   23 Z=FLOAT(NO)
C
C     COMPUTATIONS FOR THE STATISTICAL ANALYSIS ARE MADE
C
      DO 40 I=1,6
      AVRDS(I)=FLOAT(NROUND(I))/Z
      SDRD(I)=SQRT((SQN(I)/Z)-AVRDS(I)*AVRDS(I))
      AV(I)=RMIS(I)/Z
      ABSAV(I)=RABS(I)/Z
      SD(I)=SQRT((RSQ(I)/Z)-AV(I)*AV(I))
      WRITE(6,37)I
      WRITE(6,25)AVRDS(I),SDRD(I)
      WRITE(6,24)AV(I),SD(I),ABSAV(I)
   40 CONTINUE
 8000 FORMAT('1',T7,'PROBABLE ERROR IN RANGE VALUE:',F9.3)
 8002 FORMAT(' ',T7,'ERROR IN SPOT ROUND:',I3)
   37 FORMAT(' ',T7,'SIX ROUND GROUP NUMBER:',I3)
   24 FORMAT(' ',T7,'AVERAGE MISS=',F9.3,3X,'STD DEV=',F9.3,
     13X,'ABSOLUTE AVERAGE MISS=',F9.3)
   25 FORMAT(' ',T7,'AV ROUNDS=',F9.3,3X,'STD DEV=',F9.3)
      STOP
      END
```

```
ROBBINS-MONRO ONE ROUND PRECISION FIRE PROGRAM LISTING
(SIMPLE MODEL)

      DIMENSION RNG(36),RANG(36),RANGA(36),RANGSQ(36),AV(36)
     1,AVABS(36),SD(36),COUNT(36),SENSE(36),SENS(36)
C
C     UNIFORM U(0,1) RANDOM NUMBER GENERATOR IS INITIALIZED
C
      CALL OVFLOW
      KB=1
      IX=327328403
C
C     PER VALUE TO BE INVESTIGATED IS SET
C
      PER=20.0
      WRITE(6,9001)PER
C
C     NUMBER OF REPLICATIONS TO RUN IS SPECIFIED
C
      NC=1000
      NITER=36
C
C     VECTOR ARRAYS ARE ZEROED OUT
C
      DO 30 I=1,36
      RANG(I)=0.0
      RANGA(I)=0.0
      RANGSQ(I)=0.0
      AV(I)=0.0
      AVABS(I)=0.0
      SD(I)=0.0
   30 CONTINUE
      J=0
  200 J=J+1
C
C     COUNTERS ARE ZEROED OUT
C
      K=0
      N=0
      M=0
      ZZ=1.0
      IF(PER.GT.18.0)ZZ=3.0
      DO 400 I=1,36
      COUNT(I)=0.0
      SENSE(I)=0.0
      SENS(I)=0.0
  400 RNG(I)=0.0
C
C     THE INITIAL AIMPOINT LOCATION RELATIVE TO THE TARGET
C     IS ESTABLISHED. THE INITIAL AIMPOINTS WILL BE UNIFORM-
C     LY DISTRIBUTED +200, -200 METERS OF THE TRUE TARGET
C     CENTER
C
      CALL RANDOM(IX,RAN,KB)
      RANGE=RAN*200.0
      CALL RANDOM(IX,RAN,KB)
      IF(RAN.LT..5)RANGE=-RANGE
C
C     THE INITIAL SHIFT FOR ALL MISSIONS IS 200 METERS
C
      SHIFT=200.0
      TEST=50.0
      TEST1=PER*4.0
  310 M=M+1
      RUN=GRN(0)
C
C     THE BURST LOCATION IS COMPUTED
C
      RG=RUN*PER/.6745+RANGE
C
C     OBSERVER DETERMINES IF IMPACT IS OVER OR SHORT OF THE
C     TARGET
```

```
C
      SENS(M)=RG
      IF(M.GT.1)GO TO 313
  320 IF(SENS(M))311,311,312
  311 RANGE=RANGE+SHIFT
      GO TO 310
  312 RANGE=RANGE-SHIFT
      GO TO 310
C
C     OBSERVER DETERMINES IF A RANGE BRACKET HAS BEEN ESTAB-
C     LISHED
C
  313 IF(SENS(M).GT.0.0.AND.SENS(M-1).GT.0.0.OR.SENS(M).LT.0
     1.0.AND.SENS(M-1).LT.0.0)GO TO 320
C
C     THE RANGE BRACKET IS HALVED
C
      SHIFT=SHIFT*0.5
      IF(SENS(M))314,314,315
  314 RANGE=RANGE+SHIFT
      GO TO 316
  315 RANGE=RANGE-SHIFT
C
C     THE DETERMINATION TO ENTER THE FIRE FOR EFFECT PHASE
C     IS MADE
C
  316 IF(SHIFT.GT.TEST)GO TO 310
      K=K+1
      RUN=GRN(C)
      RG=RUN*PER/.6745+RANGE
      SENSE(K)=RG
  303 IF(SENSE(K))300,300,301
  300 RANGE=RANGE+TEST1/ZZ
      GO TO 302
  301 RANGE=RANGE-TEST1/ZZ
  302 K=K+1
      RUN=GRN(C)
      RG=RUN*PER/.6745+RANGE
      SENSE(K)=RG
C
C     DETERMINATION OF INITIAL FORK/ZZ BRACKET IS MADE
C
      IF(SENSE(K).GT.0.0.AND.SENSE(K-1).GT.0.0.OR.SENSE(K).L
     1T.0.0.AND.SENSE(K-1).LT.0.0)GO TO 303
  100 N=N+1
C
C     AFTER EACH POSITIVELY SENSED ROUND ZZ IS ADVANCED BY
C     ONE
C
      ZZ=ZZ+1.0
      IF(N.EQ.1)GO TO 305
      RUN=GRN(C)
      RG=RUN*PER/.6745+RANGE
  305 COUNT(N)=RG
  306 IF(COUNT(N))1,1,2
C
C     RANGE CORRECTION TO FIRE THE NEXT ROUND IS COMPUTED
C
    1 W=TEST1/ZZ
      GO TO 3
    2 W=-(TEST1/ZZ)
    3 RANGE=RANGE+W
      RNG(N)=RANGE
      IF(N.EQ.NITER)GO TO 500
      GO TO 100
  500 DO 10 I=1,36
C
C     TALLIES OF AVERAGE RANGE ERRORS AFTER EACH FIRE FOR
C     EFFECT ROUND IS MADE
C
      RANG(I)=RANG(I)+RNG(I)
      RANGA(I)=RANGA(I)+ABS(RNG(I))
```

```
      RANGSQ(I)=RANGSQ(I)+(RNG(I))*(RNG(I))
   10 CONTINUE
      IF(J-NO)200,700,700
  700 Z=FLOAT(NO)
C
C     STATISTICAL COMPUTATIONS OF REGISTRATION ERRORS ARE
C     MADE
C
      DO 20 I=1,36
      AV(I)=RANG(I)/Z
      SD(I)=SQRT((RANGSQ(I)/Z)-(AV(I))*(AV(I)))
      AVABS(I)=RANGA(I)/Z
      WRITE(6,9000)I,AVABS(I),AV(I),SD(I)
   20 CONTINUE
 9000 FORMAT(' ',T7,'ROUND=',I3,3X,'ABS AV=',F9.4,3X,'AV=',F
     19.4,3X,'SD=',F9.4)
 9001 FORMAT(' ',T7,'PROBABLE ERROR IN RANGE:',F9.4)
      STOP
      END
```

APPENDIX F FM 6-40 AND ROBBINS-MONRO ONE ROUND PRECISION FIRE SIMULATION PROGRAM LISTING

THE PURPOSE OF THIS APPENDIX IS TO PROVIDE THE COMPUTER PROGRAM LISTINGS OF THE FM 6-40 AND ROBBINS-MONRO ONE ROUND PRECISION FIRE TECHNIQUES DESCRIBED IN SECTION IV.THE ALPHABETICAL LISTING AND DESCRIPTION OF VARIABLE NAMES COMMON TO BOTH PROGRAMS IS AS FOLLOWS:

A-	TARGET SEMI-MAJOR AXIS LENGTH
ACC-	NUMBER OF METERS CORRESPONDING TO HALF S MILS AT GUN TARGET RANGE
ADJCI-	REGISTRATION RANGE ERROR
ACF-	CONTROL VARIABLE FOR ROUND OFF RULES IN COMPUTING MISS DISTANCES -2.0 NO ROUNDING OFF 2.0 ROUNDING TO NEAREST WHOLE INTEGER
AFMIS-	SUM OF ABSOLUTE REGISTRATION DEVIATION ERRORS
ANGFO-	THE TRUE ANGLE T
ANGLT-	THE OBSERVER REPORTED ANGLE T IN MILS
AFL-	DEFLECTION CORRECTION CORRESPONDING TO HALF S MILS
AVCFER-	AVERAGE REGISTRATION DEVIATION ERROR
AVJRDS-	AVERAGE NUMBER OF ROUNDS FIRED FOR A REGISTRATION
AVMRE-	THE MEAN RADIAL MISS DISTANCE OF LAST ADJUSTMENT PHASE ROUND
AVMISS-	AVERAGE RANGE ERROR OF A REGISTRATION
AVRDS-	AVERAGE NUMBER OF ROUNDS TO FIRE A REGISTRATION
AVRGER-	MEAN RANGE ERROR OF REGISTRATION
B-	TARGET SEMI-MINOR AXIS LENGTH IN METERS
BC-	GUN CREW ERROR STANDARD DEVIATION IN SETTING DEFLECTION IN 1 MIL INCREMENTS
BR-	GUN CREW ERROR STANDARD DEVIATION IN SETTING ELEVATION IN 0.1 MIL INCREMENTS
BURST-	OBSERVER ESTIMATE BURST MISS DISTANCE IN RANGE
C-	THE COMPUTED C-FACTOR

CENTER-	THE MEAN OF THE FIRE FOR EFFECT FORK BRACKET
CENTR1-	CUMULATIVE FIRE DIRECTION CENTER RANGE SHIFTS TO ATTAIN MEAN OF FORK BRACKET
CHECK-	DEVIATION ERROR CORRESPONDING TO ADJUSTED DEFLECTION
CHK-	NUMBER OF METERS CORRESPONDING TO 1 MIL AT GUN TARGET RANGE
CORR-	FIRE DIRECTION CENTER COMPUTED RANGE CORRECTION
CT-	COSINE OF ANGLE T
CT1-	COSINE OF TARGET ORIENTATION ANGLE
CTFC-	COSINE OF TRUE ANGLE T
DAV-	MEAN ABSOLUTE DEFLECTION ERROR OF A REGISTRATION
DEF-	KEEPS TRACK OF INITIAL DEFLECTION PRIOR TO FORCING A DEFLECTION BRACKET
DEFAPL-	CUMULATIVE SUM OF DEFLECTION CORRECTIONS
DEFCHK-	SUBROUTINE WHICH DETERMINES IF ADJUSTED DEFLECTION HAS BEEN ACHIEVED
DEFLEC-	DEFLECTION DIFFERENCE BETWEEN AIM POINT AND TRUE TARGET CENTER IN METERS
DEFTRY-	DEFLECTION CORRECTION TRIAL COUNTER
DF-	GUN TARGET BURST DEFLECTION MISS DISTANCE IN METERS
DFAV-	MEAN ABSOLUTE DEFLECTION MISS DISTANCE OF LAST ADJUSTMENT PHASE ROUND
DFMISS-	SUM OF REGISTRATION DEVIATION ERRORS
DFSQ-	SUM OF SQUARES OF REGISTRATION DEVIATION ERRORS
DIF-	THE DIFFERENCE OF OVER AND SHORT SPOTS AT COMPLETION OF REGISTRATION
DM-	MEAN ABSOLUTE REGISTRATION DEVIATION ERROR
DMIS-	SUM OF REGISTRATION ABSOLUTE DEVIATION ERRORS
DTSQ-	SUM OF SQUARES OF REGISTRATION RADIAL ERRORS
EIGHT-	NUMBER OF METERS CORRESPONDING TO 8 MILS AT GUN TARGET RANGE

FDCDF- FIRE DIRECTION CENTER DEFLECTION MISS DISTANCE

FDCRG- FIRE DIRECTION CENTER RANGE MISS DISTANCE

FDCFS- FIRE DIRECTION CENTER LEFT, RIGHT, AND DOUBTFUL SPOTS

FDCFS1- VECTOR ARRAY WHICH TRACKS ALL POSITIVE FIRE DIRECTION CENTER DEFLECTION SPOTS IF ADJUSTED DEFLECTION HAS NOT BEEN ACHIEVED BUT ADJUSTED RANGE HAS

FDRGS- FIRE DIRECTION CENTER OVER, SHORT, AND DOUBTFUL SPOTS

FFEDF1- SUM OF ABSOLUTE DEFLECTION MISS DISTANCES OF LAST ADJUSTMENT PHASE ROUNDS

FEDFSQ- SUM OF SQUARES OF FFEDF1

FFERG1- SUM OF ABSOLUTE RANGE MISS DISTANCES OF LAST ADJUSTMENT PHASE ROUNDS

FERGSQ- SUM OF SQUARES OF FFERG1

FIVE- NUMBER OF METERS CORRESPONDING TO 5 MILS AT GUN TARGET RANGE

FOANER- THE STANDARD DEVIATION OF ANGLE T ERROR IN MILS

FODCR- OBSERVER DEFLECTION CORRECTION

FODF- BURST DEVIATION MISS DISTANCE IN METERS IN THE OBSERVER TARGET COORDINATE SYSTEM

FODFS- OBSERVER LEFT, RIGHT, AND LINE SPOTS

FORG- BURST RANGE MISS DISTANCE IN METERS IN THE OBSERVER TARGET COORDINATE SYSTEM

FORG1- OBSERVER SPOT OF RANGE BURST IN ADJUSTMENT PHASE

FORGS- OBSERVER OVER,SHORT, AND DOUBTFUL SPOTS

FORKFS- THE VALUE OF FIRE FOR EFFECT FORK TO NEAREST EVEN MIL

FORKTR- THE VALUE OF TABULAR FIRING TABLE FORK TO NEAREST MIL

FOUR- NUMBER OF METERS CORRESPONDING TO 4 MILS AT GUN TARGET RANGE

ICHG- POWDER CHARGE PARAMETER

ICC-	CONTROL VARIABLE FOR SPECIFYING ANGLE T
IDOUT-	DOUBTFUL RANGE SPOT COUNTER
IGOOD-	CORRECT ADJUSTED DEFLECTION INDICATOR
IONE-	TARGET HIT INDICATOR
IOPP-	INDICATOR OF DEFLECTION BRACKET EXISTENCE
IOR-	OVER RANGE SPOT COUNTER
IOVR1-	OVER RANGE SPOT COUNTER
IOVER -	OVER RANGE SPOT COUNTER
IOVER1-	OVER RANGE SPOT COUNTER
IOVER2-	OVER RANGE SPOT COUNTER
IRDS-	SUM OF ALL ROUNDS FIRED
ISHIFT-	OBSERVER RANGE SHIFT
ISH-	SHORT RNAGE SPOT COUNTER
ISHORT-	SHORT RNAGE SPOT COUNTER
ISHRT1-	SHORT RNAGE SPOT COUNTER
ISHT1-	SHORT RNAGE SPOT COUNTER
ISHT2-	SHORT RNAGE SPOT COUNTER
J-	ADJUSTMENT PHASE ROUND COUNTER
JJ-	OBSERVER ADJUSTMENT PHASE POSITIVE RANGE SPOT COUNTER
JRDS-	SUM OF FIRE FOR EFFECT ROUNDS
JSQ-	SUM OF SQUARES OF JRDS
K-	ROUND COUNTER
KA-	OBSERVER ADJUSTMENT PHASE 'LINE' SPOT COUNTER
KF-	FIRE DIRECTION POSITIVE DEFLECTION SPOT COUNTER
KN-	ROUND COUNTER
KTGT-	TARGET HIT INDICATOR
LTGTS-	CUMULATIVE TOTAL NUMBER OF TARGETS STRUCK
MISDIS-	RADIAL ERROR OF A REGISTRATION IN METERS
MISTOT-	SUM TOTAL OF ALL RADIAL ERRORS
MRE-	RADIAL MISS DISTANCE OF LAST ADJUSTMENT ROUND
MRE1-	SUM OF RADIAL MISS DISTANCES OF LAST ADJUSTING ROUNDS
MRSQ-	SUM OF SQUARES OF MRE1

MTGT- DESIGNATOR FOR TYPE OF MISSION TO EVALUATE
0 IMPLIES REGISTRATION
1 IMPLIES DESTRUCTION
N- FIRE FOR EFFECT ROUND COUNTER
NI- TOTAL REPLICATION COUNTER
NITER- POSITEVELY SPOTTED ROUND
NN- ROUND COUNTER
NODEF- INDICATES THAT DEFLECTION BRACKET DOES NOT EXIST
NOGOOD- COUNTER FOR ELIMINATED 5AND1 REGISTRATIONS
NONE- INDICATES THAT NO POSITIVE FIRE DIRECTION CENTER DEFLECTION SPOT EXISTS
NOPREP- NO PREPONDERANCE OF OVER AND SHORT RANGE SPOTS
NOTRGT- NUMBER OF TARGETS STRUCK
NRFRD- NUMBER OF ROUNDS FIRED
NROUND- TOTAL NUMBER OF ROUNDS TO FIRE FOR EACH REGISTRATION
NTGT- TARGET HIT COUNTER
ONE- NUMBER OF METERS CORRESPONDING TO 1 MIL AT GUN TARGET RANGE
OTHER- THE DATA IN METERS CORRESPONDING TO APPROPRIATE END OF FORK BRACKET AT WHICH THE SECOND GROUP OF THREE ROUNDS WERE FIRED
OTHER1- THE CUMULATIVE FIRE DIRECTION CENTER RANGE SHIFTS TO ATTAIN 'OTHER'
OTRG- THE OBSERVER TARGET RANGE IN METERS
PED- PROBABLE ERROR IN DEFLECTION
PER- PROBABLE ERROR IN RANGE
POS- OBSERVER POSITIVE RANGE SPOT IN ADJUSTMENT PHASE
R- SPECIFIES HOW ELEVATION IS TO BE APPLIED
-1.0 IMPLIES TO NEAREST .1 MILS
1.0 IMPLIES TO NEAREST 1 MIL
RANGE- RANGE DIFFERENCE BETWEEN AIMPOINT AND TRUE TARGET CENTER IN METERS
RG- GUN TARGET RANGE MISS DISTANCE OF BURST

RG1-	BURST RANGE MISS DISTANCE IN TARGET COORDINATE SYSTEM
RAV-	MEAN ABSOLUTE RANGE ERROR OF A REGISTRATION
RGAV-	MEAN ABSOLUTE RANGE MISS DISTANCE OF LAST ADJUSTMENT PHASE ROUND
RGMISS-	SUM OF REGISTRATION RANGE ERRORS
RGSQ-	SUM OF SQUARES OF REGISTRATION RANGE ERRORS
RM-	MEAN ABSOLUTE RANGE ERROR OF A REGISTRATION
RN-	TABULAR FIRING TABLE GUN TARGET RANGE
SDAVD-	STANDARD DEVIATION OF DFAV
SDAVR-	STANDARD DEVIATION OF RGAV
SDDF-	STANDARD DEVIATION OF AVERAGE REGISTRATION DEVIATION ERRORS
SDJR-	STANDARD DEVIATION OF ROUNDS FIRED FOR A REGISTRATION
SDMD-	STANDARD DEVIATION OF DEVIATION ERRORS OF A REGISTRATION
SDRD-	STANDARD DEVIATION OF AVRDS
SDRG-	STANDARD DEVIATION OF AVERAGE RANGE ERRORS OF A REGISTRATION
SHIFT-	OBSERVER RANGE SHIFT
SHFTDF-	FIRE DIRECTION CENTER DEFLECTION SHIFT
SHFTRG-	FIRE DIRECTION CENTER RANGE SHIFT
SIXTEN-	NUMBER OF METERS CORRESPONDING TO 16 MILS AT GUN TARGET RANGE
START-	RANDOM NUMBER GENERATOR INITIALIZER
ST-	SIN OF ANGLE T
ST1-	SIN OF TARGET ORIENTING ANGLE
STFC-	SIN OF TRUE ANGLE T
TETAFO-	TRUE ANGLE T IN RADIANS
TGTANG-	TARGET SEMI-MAJOR AXIS ANGULAR ORIENTATION IN MILS
THETA-	ANGLE T IN RADIANS
THETA1-	TARGET ORIENTING ANGLE IN RADIANS
TWO-	NUMBER OF METERS CORRESPONDING TO 2 MILS AT GUN TARGET RANGE

TWOPI- TWO PI

WDF- PROBABILITY OF OBSERVER DEVIATION SPOT ERROR

WRG- PROBABILITY OF OBSERVER RANGE SPOT ERROR

YDF- PROBABILITY OF OBSERVER DEVIATION SPOT ERROR

YRG- PROBABILITY OF OBSERVER RANGE SPOT ERROR

ZDF- INDICATOR TO APPLY OBSERVER SPOT ERROR IN DEVIATION

-1.0 INDICATES ERROR TO BE APPLIED

+1.0 INDICATES ERROR NOT APPLIED

ZIL- A MISSION COUNTER

ZN- FRACTION OF 'PREPONDERANCE' FORMULA TO USE IN COMPUTING TARGET DESTRUCTION DATA

ZRG- INDICATOR TO APPLY OBSERVER SPOT ERROR IN RANGE

-1.0 INDICATES ERROR TO BE APPLIED

+1.0 INDICATES ERROR NOT APPLIED

```
C     PROGRAM LISTING OF THE FM-6-40 PRECISION FIRE
C     PROCEDURE
C
C     USER INFORMATION.
C     THE PROGRAM AS WRITTEN WILL INVESTIGATE ONLY THE
C     FOLLOWING AMMUNITION PARAMETER INPUTS EXTRACTED FROM
C     FIRING TABLES TFT 155-AH-2
C
C     CHARGE     RANGE(RN)    ICHG    PER     PED
C      5GB        2000         59       7      1
C      5WB        5500         51      20      3
C      5GB        6000          5      13      3
C      6          8000          6      27      4
C      6         10000         61      34      5
C
C     FOR OTHER PARAMETER VALUES THE USER MUST MAKE APPRO-
C     PRIATE CHANGES TO FORKF, FORKT, AND OFCTR ROUTINES
C
C     THE USER MUST SPECIFY THE FOLLOWING INPUT PARAMETERS:
C
C     A-       THE TARGET SEMIMAJOR AXIS IN METERS
C     B-       THE TARGET SEMIMINOR AXIS IN METERS
C     TGTANG-  THE TARGET ORIENTING ANGLE IN MILS
C     MTGT-    SET MTGT=0 IF REGISTRATION DESIRED
C              SET MTGT=1 IF DESTRUCTION DESIRED
C     ADP-     SET ADP=1 TO SIMULATE FIRE DIRECTION CENTER
C              RANGE CORRECTIONS TO NEAREST 10 METERS
C     ANGLT-   SPECIFY THE ANGLE T TO BE INVESTIGATED IN MILS
C     HALFS-   INSERT THE APPROPRIATE HALFS VALUE SPECIFIED
C              FOR ANGLE T
C     FOANER-  SPECIFY THE STANDARD DEVIATION OF OBSERVER
C              ANGLE T ERROR IN MILS
C     YRG-     SPECIFY PROBABILITY OF OBSERVER RANGE SPOT
C              ERROR IN ADJUSTMENT PHASE
C     YDF-     SET PROBABILITY OF OBSERVER DEFLECTION SPOT
C              ERROR IN ADJUSTMENT PHASE
C     WRG-     SPECIFY PROBABILITY OF OBSERVER RANGE SPOT
C              ERROR IN FIRE FOR EFFECT PHASE
C     WDF-     SET PROBABILITY OF OBSERVER DEFLECTION SPOT
C              ERROR IN FIRE FOR EFFECT PHASE
C     ZRG,ZDF-SET TO -1.0 IF OBSERVER SPOT ERROR PROBABILI-
C              TIES ARE TO BE APPLIED;+1.0  IF NO OBSERVER
C              SPOT ERROR IS DESIRED
C     BR,BD-   DUMMY VARIABLES WHICH MUST BE SET TO 0.0
C     OTRG-    THE OBSERVER TARGET RANGE
C     ICHG-    THE POWDER TYPE AND CHARGE
C     RN-      THE RANGE IN METERS TO GO WITH ICHG
C     PER-     APPROPRIATE PROBABLE ERROR IN RANGE CORRES-
C              PONDING TO ICHG
C     PED-     APPROPRIATE PROBABLE ERROR IN DEFLECTION CORR-
C              ESPONDING TO ICHG
C
      LOGICAL LESS
      REAL MRE1,MRSQ,MRE,MISDIS,MISTOT,OTRG
      DIMENSION POS(50),FDDFS1(50)
      COMMON TABLEA(50,3),KA,KF,ACC,RN,DEFLEC,IGOOD,ONE,TWO,
     1FOUR,FIVE,EIGHT,SIXTEN,NODEF,IOPP
      IDD=-2
C
C     MISSION TYPE IS SPECIFIED
C
      MTGT=0
      ADP=1.0
C
C     THE AMMUNITION PARAMETERS TO BE INVESTIGATED ARE SET
C
      ICHG=5
      RN=6000.0
      PER=13.0
      PED=3.0
C
C     ANGLE T AND APPROPRIATE HALFS IS SPECIFIED
```

```
C
      ANGLT=600.0
      HALFS=4.0
      GO TO 502
  500 CONTINUE
      ANGLT=800.0
      HALFS=4.0
      GO TO 502
  501 CONTINUE
      ANGLT=1600.0
      HALFS=8.0
  502 TWOPI=6.283184
      IDO=IDO+1
C
C     TARGET PARAMTERS ARE SPECIFIED
C
      A=5.0
      B=5.0
      TGTANG=0.0
      THETA1=(TGTANG/6400.0)*TWOPI
      ST1=SIN(THETA1)
      CT1=COS(THETA1)
C
C     COUNTERS AND VECTOR ARRAYS FOR ALL MISSIONS ARE ZEROED
C
      NI=0
      NCTRGT=0
      RGMISS=0.0
      DFMISS=0.0
      RMIS=0.0
      DMIS=0.0
      IRDS=0.0
      MRE1=0.0
      MRSQ=0.0
      FFERG1=0.0
      FFEDF1=0.0
      FERGSQ=0.0
      FEDFSQ=0.0
      NOGOOD=0
      JRDS=0
      JSQ=0
      DTSQ=0
      RGSQ=0
      DFSQ=0
      RDSQ=0
      MISTOT=0
C
C     OBSERVER TARGET DISTANCE IS SET
C
      OTRG=2500
C
C     THETA IS CONVERSION OF ANGLE T FROM MILS TO RADIANS.
C
      THETA=(ANGLT/6400.0)*TWOPI
      ST=SIN(THETA)
      CT=COS(THETA)
C
C     THE RANDOM NUMBER GENERATOR IS INITIALIZED.
C
      START=RAN(-351)
C
C     PARAMETER TEST IS USED TO DETERMINE WHEN TO ENTER INTO
C     FIRE FOR EFFECT PHASE.
C
      TEST1=100.0
      TEST=50.0
      IF(PER.GT.38.0)TEST=100
  200 NI=NI+1
C
C     THE OBSERVER SPOT ERROR PARAMTERS ARE SPECIFIED
C
      WDF=0.0
```

```
      WRG=0.0
      YRG=0.05
      YDF=0.02
      ZRG=1.0
      ZDF=1.0
      BR=0.0
      BD=0.0
C
C     THE OBSERVER ANGLE T ERROR IS APPLIED TO DETERMINE THE
C     TRUE ANGLE T
C
      FCANER=0.0
      ANGFO=ANGLT+(RAN(0))*FCANER
      TETAFO=(ANGFO/6400.0)*TWOPI
      STFO=SIN(TETAFO)
      CTFO=COS(TETAFO)
C
C     THE INITIAL BURST LOCATION AT START OF EACH MISSION IS
C     ESTABLISHED. IT IS ASUMED THAT THE INITIAL ROUND WILL
C     BE UNIFORMLY DISTRIBUTED IN AN 800 BY 400 METER RECT-
C     ANGLE CENTERED ON THE TRUE TARGET CENTER
C
      RANGE=RAN(1)*400.0
      IF(RAN(1).LT..5)RANGE=-RANGE
      DEFLEC=RAN(1)*200.0
      IF(RAN(1).LT..5)DEFLEC=-DEFLEC
C
C     COUNTERS AND VARIABLES FOR EACH MISSION ARE ZEROED
C
      DEF=0.0
      ICVR2=0
      ICVR1=0
      ISHT2=0
      ISHT1=0
      ICVER=0
      ISHORT=0
      ICVER1=0
      ISHRT1=0
      IDOUBT=0
      IDOUT=0
      IGOOD=0
      K=0
      KA=0
      KF=0
      KN=0
      NN=0
      J=0
      JJ=0
      N=0
      NCPREP=0
      KTGT=0
      NTGT=0
      IONE=0
      DEFAPL=0.0
      RGSHFT=0.0
      FCCOR=0.0
      SHIFT=0.0
      IOPP=0
      NCDEF=0
      ADD=HALFS*RN*0.001
      CHK=RN*0.001
      ONE=CHK
      TWO=CHK*2.0
      FOUR=CHK*4.0
      FIVE=CHK*5.0
      EIGHT=CHK*8.0
      SIXTEN=CHK*16.0
      DO 99 I=1,50
      FCS(I)=0
      FDDFS1(I)=0
   99 CONTINUE
      DO 400 IM=1,50
```

```
      DO 400 MM=1,3
  400 TABLEA(IN,MM)=0.0
      R=1.0
      ISHIFT=1000
C
C     THE ADJUSTMENT PHASE IS ENTERED
C
C
C
C     THE OBSERVER CORRECTIONS ARE TRANSFERED TO THE GUN
C     TARGET COORDINATE SYSTEM
C
    1 SHFTDF=ROTGND(FOCOR,SHIFT,ST,CT)
      SHFTRG=ROTGNR(FOCOR,SHIFT,ST,CT)
      IF(ADP.GT.0.0)SHFTRG=RDOFF(SHFTRG)
C
C     THE C-FACTOR IS COMPUTED
C
      C=CFCTR(RN,RGSHFT,ICHG)
C
C     TOTAL RANGE CORRECTIONS ARE COMPUTED
C
      RGSHFT=RGSHFT+SHFTRG
C
C     RANGE AND DEFLECTION CORRECTIONS ARE APPLIED;THE AIM
C     POINT CORRESPONDING TO ELEVATION AND DEFLECTION COR-
C     RECTIONS IS COMPUTED
C
      RANGE=RANGE+FDCRCR(SHFTRG,C,BR,R)
      DEFLEC=DEFLEC+FDCDCR(RN,RANGE,SHFTDF,BD)
C
C     OBSERVER SPOT ERROR IS CHANGED FROM ADJUSTMENT ERROR
C     TO FIRE FOR EFFECT ERROR.IT IS ASSUMED THAT THE PRO-
C     BABILITY OF OBSERVER SPOT ERROR WILL BE GREATER IN THE
C     FIRE FOR EFFECT PHASE
C
      IF(IABS(ISHIFT).LE.TEST1)WDF=YDF
      IF(IABS(ISHIFT).LE.TEST1)WRG=YRG
C
C     DETERMINATION TO ENTER THE FIRE FOR EFFECT PHASE IS
C     MADE
C
      IF(IABS(ISHIFT).LE.TEST)GO TO 101
      J=J+1
C
C     ACTUAL BURST LOCATION IN GUN-TARGET COORDINATE SYS-
C     TEM IS COMPUTED
C
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
C
C     ACTUAL BURST IMPACT LOCATION IN THE TARGET COORDINATE
C     SYSTEM IS ESTABLISHED
C
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
C
C     THE BURST IMPACT AS THE OBSERVER SEES IT IN THE OBSER-
C     VER COORDINATE SYSTEM IS COMPUTED
C
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(J.GT.1)GO TO 64
C
C     THE OBSERVER DETERMINES THE INITIAL RANGE SHIFT TO USE
C     IN THE ADJUSTMENT PHASE
C
      BURST=RDOFF(ERRFCN(OTRG,FORG))
      ISHIFT=ISHFTS(ABS(BURST))
C
C     A DETERMINATION OF TARGET HIT IS MADE
C
   64 IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)IONE=1
```

```
   31 IDOUBT=IDOUBT+1
      NT=NT-1
      GO TO 29
   32 IOVER=IOVER+1
      GO TO 34
   33 IOVER=IOVER+1
      ISHORT=ISHORT+1
      IGOOD=1
      NTGT=NTGT+1
      IF(MTGT.EQ.1)GO TO 58
   34 IF(NT-2)29,29,35
   35 IPOS=IOVER+ISHORT
C
C     THREE POSITIVE FIRE DIRECTION CENTER RANGE SPOTS HAVE
C     BEEN ACHIEVED AT THE MEAN OF THE FORK BRACKET
C
      IF(3-IPOS)36,36,29
C
C     PREPONDERANCE OF OVER AND SHORT SPOTS IS DETERMINED
C
   36 IF(IOVER-ISHORT)37,38,39
   37 C=CFCTR(RN,RGSHFT,ICHG)
      SHFTRG=FORKFS*0.5*100.0/C
      RGSHFT=RGSHFT+SHFTRG
      RANGE=RANGE+SHFTRG
      GO TO 40
C
C     NO PREPONDERANCE EXISTS; THE SECOND GROUP OF THREE
C     POSITIVE RANGE ROUNDS IS ATTAINED BY FIRING AT PREVI-
C     OUS ELEVATION DATA
C
   38 NOPREP=1
      GO TO 40
   39 C=CFCTR(RN,RGSHFT,ICHG)
      SHFTRG=-FORKFS*0.5*100.0/C
      RGSHFT=RGSHFT+SHFTRG
      RANGE=RANGE+SHFTRG
   40 OTHER=RANGE
      OTHER1=RGSHFT
      IDOUT1=0
      IF(NOPREP.EQ.1)GO TO 93
C
C     A TARGET HIT WAS ATTAINED IN ADJUSTMENT PHASE OR IN
C     ESTABLISHING THE INITIAL FORK BRACKET.IF A PREPONDER-
C     ANCE EXISTS, SUFFICIENT ROUNDS ARE FIRED TO ACHIEVE
C     THREE POSITIVE FIRE DIRECTION CENTER RANGE SPOTS AT
C     DATA 1/2 FORK OPPOSITE TO PREPONDERANCE OF FIRST GROUP
C     OF ROUNDS
C
      IF(KTGT.EQ.1)GO TO 93
C
C     BASED ON SPOT PREPONDERANCE, THE APPROPRIATE END OF
C     THE FORK BRACKET IS USED TO FIRE SUFFICIENT NUMBER OF
C     OF ROUNDS TO ACHIEVE TWO POSITIVE FIRE DIRECTION CEN-
C     TER RANGE SPOTS. A BUFFER OF ONE PER IS USED TO
C     PROTECT AGAINST COMPUTER ROUND OFF ERRORS TO ENSURE
C     PROPER END OF FORK BRACKET IS USED
C
      IF(ABS(OTHER-RANGE2).LT.PER)GO TO 91
      GO TO 90
   90 IOVER1=IOVR1
      ISHRT1=ISHT1
      GO TO 92
   91 IOVER1=IOVR2
      ISHRT1=ISHT2
   92 NS=1
      GO TO 41
   93 NS=0
   41 N=N+1
      NS=NS+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
```

```
C     EXISTENCE OF A FORK BRACKET IS DETERMINED
C
   54 IF(FDRGS.LT.0.0.AND.LESS.OR.FDRGS.GT.0.0.AND..NOT.
     1LESS)GO TO 15
C
C     THE FORK BRACKET HAS BEEN ACHIEVED;THE APPROPRIATE
C     1/2 FORK SHIFT IS APPLIED
C
      IF(FDRGS)16,17,18
   16 RANGE2=RANGE
      ISHT2=1
      IOVR2=0
      C=CFCTR(RN,RGSHFT,ICHG)
      SHFTRG=FORKFS*0.5*100.0/C
      RGSHFT=RGSHFT+SHFTRG
      RANGE=RANGE+SHFTRG
      GO TO 19
   17 IDOUT=IDOUT+1
      GO TO 14
   18 RANGE2=RANGE
      IOVR2=1
      ISHT2=0
      C=CFCTR(RN,RGSHFT,ICHG)
      SHFTRG=-FORKFS*0.5*100.0/C
      RGSHFT=RGSHFT+SHFTRG
      RANGE=RANGE+SHFTRG
   19 NT=0
      CENTER=RANGE
      CENTR1=RGSHFT
      GO TO 29
C
C     A TARGET HIT WAS ACHIEVED IN EITHER THE ADJUSTMENT
C     PHASE OR IN ESTABLISHING THE INITIAL FORK BRACKET;THIS
C     REQUIRES TWO ADDITIONAL POSITIVE RANGE ROUNDS TO BE
C     FIRED TO ATTAIN THE INITIAL GROUP OF THREE POSITIVE
C     FIRE DIRECTION CENTER RANGE SPOTS
C
   28 IOVER=IOVER+1
      ISHORT=ISHORT+1
      NTGT=NTGT+1
      IF(MTGT.EQ.1)GO TO 58
  102 CENTER=RANGE
      CENTR1=RGSHFT
      CHECK=DEFLEC
      IGOOD=1
      NT=1
      KTGT=1
C
C     FIRING AT THE MEAN OF THE FORK BRACKET IS CONDUCTED
C
   29 N=N+1
      NT=NT+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 33
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
      FDRGS=RNGSNS(ANGLT,FORGS,FODFS)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(IGOOD.EQ.1)GO TO 55
      IF(FDDFS.EQ.0.0)GO TO 55
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
      CALL DEFCHK
   55 IF(FDRGS)30,31,32
   30 ISHORT=ISHORT+1
      GO TO 34
```

```
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 28
C
C     OBSERVER SPOTS PRIMARY QUADRANT LOCATION OF BURST
C
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
C
C     OBSERVER SPOTS ARE CONVERTED TO FIRE DIRECTION SPOTS
C
      FDRGS=RNGSNS(ANGLT,FORGS,FODFS)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(IGOOD.EQ.1)GO TO 15
C
C     DEFLECTION CORRECTIONS AND DETERMINATION OF ADJUSTED
C     DEFLECTION ARE MADE BY SUBROUTINE DEFCHK
C
      IF(FDDFS.EQ.0.0)GO TO 15
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
      CALL DEFCHK
C
C     APPROPRIATE FORK RANGE SHIFTS ARE APPLIED TO ESTABLISH
C     THE INITIAL FORK BRACKET
C
   15 IF(FDRGS)11,12,13
   11 LESS=.TRUE.
      RANGE1=RANGE
      ISHT1=1
      ICVR1=0
      C=CFCTR(RN,RGSHFT,ICHG)
      SHFTRG=FORKFS*100.0/C
      RGSHFT=RGSHFT+SHFTRG
      RANGE=RANGE+SHFTRG
      GO TO 14
   12 IDOUT=IDOUT+1
      GO TO 10
   13 LESS=.FALSE.
      RANGE1=RANGE
      ICVR1=1
      ISHT1=0
      C=CFCTR(RN,RGSHFT,ICHG)
      SHFTRG=-FORKFS*100.0/C
      RGSHFT=RGSHFT+SHFTRG
      RANGE=RANGE+SHFTRG
C
C     FIRING TO ESTABLISH THE INITIAL FORK BRACKET IS DONE
C
   14 N=N+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 28
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
      FDRGS=RNGSNS(ANGLT,FORGS,FODFS)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(IGOOD.EQ.1)GO TO 54
      IF(FDDFS.EQ.0.0)GO TO 54
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
      CALL DEFCHK
C
```

```
      IF(IONE.EQ.1)GO TO 101
C
C     OBSERVER DETERMINES DEVIATION CORRECTIONS
C
      FOCOR=-RDOFF(ERRDF(CTRG,FODF))
C
C     OBSERVER DETERMINES RANGE SPOT OF BURST
C
      FORG1=OBTSNS(FORG,FODF,ZRG,WRG)
      IF(FOCOR)2,3,2
C
C     IF DEVIATION CORRECTION IS GREATER THAN 100 METERS,
C     THE OBSERVER REQUESTS ONLY A DEVIATION SHIFT
C
    2 IF(ABS(FOCOR).GT.100.0)SHIFT=0.0
      IF(ABS(FOCOR).GT.100.0)GO TO 1
      GO TO 4
C
C     OBSERVER SPOTS A LINE BURST.FIRE DIRECTION CENTER
C     DEFLECTION AND DEFLECTION SPOT ARE RECORDED FOR FUTURE
C     REFERENCE FOR DETERMINING CORRECT DEFLECTION IN FIRE
C     FOR EFFECT PHASE
C
    3 KA=KA+1
      KF=KF+1
      TABLEA(KF,2)=DEFSNS(ANGLT,FORG1,FOCOR)
      TABLEA(KF,3)=DEFLEC
    4 IF(FORG1)7,6,7
    6 SHIFT=0.0
C
C     IF TWO OR MORE OBSERVER POSITIVE RANGE ROUNDS HAVE
C     BEEN OBSERVED AND DEVIATION CORRECTION IS LESS THAN
C     50 METERS, FIRE FOR EFFECT PHASE IS ENTERED.
C
      IF(JJ.GT.1.AND.ABS(FOCOR).LT.50.0)ISHIFT=TEST
      GO TO 1
    7 JJ=JJ+1
      POS(JJ)=FORG1
      IF(JJ.GT.1)GO TO 8
      GO TO 9
C
C     OBSERVER DETERMINES IF A RANGE BRACKET EXISTS
C
    8 IF(POS(JJ).GT.0.0.AND.POS(JJ-1).GT.0.0.OR.POS(JJ).LT.0
     1.0.AND.POS(JJ-1).LT.0.0)GO TO 9
C
C     THE RANGE BRACKET IS HALVED
C
      ISHIFT=ISHIFT*0.5
    9 IF(POS(JJ).GT.0.0)GO TO 60
      SHIFT=FLOAT(ISHIFT)
      GO TO 1
   60 SHIFT=-FLOAT(ISHIFT)
      GO TO 1
C
C     THE FIRE FOR EFFECT PHASE IS ENTERED
C
  101 FFERG=RG
      FFEDF=DF
      WRG=YRG
      WDF=YDF
C
C     TWO FORK VALUES ARE COMPUTED;THE FIRE FOR EFFECT FORK
C     (FORKFS) TO NEAREST EVEN MIL AND THE COMPUTATIONAL
C     FORK (FORKTR) TO NEAREST MIL USED IN DERIVING THE AD-
C     JUSTED RANGE CORRECTIONS AT END OF REGISTRATION
C
      FORKFS=FORKF(RN,RGSHFT,ICHG)
      FORKTR=FORKT(RN,RGSHFT,ICHG)
      IF(IONE.EQ.1)GO TO 28
   10 N=N+1
      RG=(RAN(0))*PER/.6745+RANGE
```

```
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 45
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
      FDRGS=RNGSNS(ANGLT,FORGS,FODFS)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(IGOOD.EQ.1)GO TO 56
      IF(FDDFS.EQ.0.0)GO TO 56
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
      CALL DEFCHK
   56 IF(FDRGS)42,43,44
   42 ISHRT1=ISHRT1+1
      GO TO 46
   43 IDOUT1=IDOUT1+1
      NS=NS-1
      GO TO 41
   44 IOVER1=IOVER1+1
      GO TO 46
   45 ISHRT1=ISHRT1+1
      IOVER1=IOVER1+1
      NTGT=NTGT+1
      IF(MTGT.EQ.1)GO TO 58
   46 IF(NS-2)41,41,47
   47 IPCS1=IOVER1+ISHRT1
      IF(3-IPCS1)48,48,41
C
C     THE REGISTRATION FIRING FOR RANGE CORRECTIONS IS COM-
C     PLETE
C
   48 ISHORT=ISHORT+ISHRT1
      IOVER=IOVER+IOVER1
C
C     ALL 5 AND 1 RANGE SPOT REGISTRATIONS ARE REFIRED
C
      IF(ISHORT.GT.1.AND.IOVER.GT.1)GO TO 82
      NOGOOD=NOGOOD+1
      NI=NI-1
      GO TO 200
C
C     THE ADJUSTED RANGE CORRECTION DATA IS COMPUTED BY THE
C     PREPONDERANCE FORMULA
C
   82 RGSHFT=(CENTR1+OTHER1)/2.0
      R=-1.0
      C=CFCTR(RN,RGSHFT,ICHG)
      DIF=(ISHORT-IOVER)
      CORR=DIF*(FORKTR*100.0/C)/12.0
      CORR=FDCRCR(CORR,C,BR,R)
      ADJCI=((CENTER+OTHER)/2.0)+CORR
C
C     THE REGISTRATION RANGE ERROR IS RECORDED
C
      RANGE=ADJCI
      RGSHFT=RGSHFT+CORR
      IF(MTGT.EQ.1)GO TO 86
   74 IF(IGOOD.EQ.1)GO TO 58
C
C     IF CRITERIA FOR ADJUSTED DEFLECTION HAS NOT BEEN MET,
C     FIRING IS CONTINUED USING ADJUSTED ELEVATION DATA UN-
C     TIL ADJUSTED DEFLECTION IS ACHIEVED
C
      NN=NN+1
      N=N+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
```

```
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 88
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      FDDFS1(NN)=FDDFS
      IF(NN.EQ.1)GO TO 59
C
C     IF TWO DOUBTFUL DEFLECTION SPOTS ARE ATTAINED IN SUC-
C     CESSION AND A DEFLECTION BRACKET EXISTS, THE DEFLECT-
C     ION IS CONSIDERED CORRECT
C
      IF(FDDFS1(NN).EQ.0.0.AND.FDDFS1(NN-1).EQ.0.0)GO TO 57
   59 IF(FDDFS.EQ.0.0)GO TO 74
      KF=KF+1
      TABLEA(KF,3)=DEFLEC
      TABLEA(KF,2)=FDDFS
      CALL DEFCHK
      IF(IGOOD.EQ.1)GO TO 58
      GO TO 74
   57 IF(IOPP.EQ.1)GO TO 58
C
C     A DEFLECTION BRACKET IS FORCED. THE MEAN OF THE DEF-
C     LECTION BRACKET IS TAKEN AS THE ADJUSTED DEFLECTION
C
      NODEF=1
      NONE=0
      IF(KA.EQ.0.AND.KF.EQ.0)GO TO 600
  700 IF(TABLEA(KF,2).GT.0)GO TO 150
      NONE=0
      GO TO 151
  600 NONE=1
      APL=ABS(ADD)
      GO TO 71
  151 APL=ABS(ADD)
      GO TO 71
  150 APL=-ABS(ADD)
      NONE=0
   71 DEFLEC=DEFLEC+APL
      DEFAPL=DEFAPL+APL
      DEF=DEFLEC-DEFAPL
   72 N=N+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(RG,DF,ST1,CT1)
      DF1=ROTFOD(RG,DF,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 88
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(FDDFS.EQ.0.0)GO TO 57
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
      CALL DEFCHK
      IF(IOPP.EQ.1)GO TO 58
      IF(NONE.EQ.1)DEFLEC=DEF
      IF(NONE.EQ.1)GO TO 700
      IF(NONE.EQ.0)GO TO 72
C
C     IF TARGET DESTRUCTION IS BEING INVESTIGATED AND TARGET
C     HIT HAS NOT BEEN ACHIEVED IN 'REGISTRATION' PORTION,
C     THEN SUCCESSIVE GROUPS OF SIX ROUNDS ARE FIRED UNTIL
C     TARGET HIT IS ATTAINED
C
   86 NF=0
      NITER=1
      ICR=0
      ISH=0
```

```
      RANGE=ADJCI
      DEFTRY=0.0
   85 N=N+1
      IF(N.GT.100)GO TO 200
      NF=NF+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 88
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
      FDRGS=RNGSNS(ANGLT,FORGS,FODFS)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(FDDFS.EQ.0.0)GO TO 170
      IF(IGOOD.EQ.1)GO TO 175
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
      CALL DEFCHK
      IF(IGOOD.EQ.0)GO TO 170
  175 APPLDF=ONE
      IF(FDDFS.GT.0.0)GO TO 176
      DEFLEC=DEFLEC+APPLDF
      GO TO 170
  176 DEFLEC=DEFLEC-APPLDF
  170 IF(FDRGS)171,172,173
  172 NF=NF-1
      GO TO 85
  171 ISH=ISH+1
      IF(NF.EQ.6)GO TO 174
      GO TO 85
  173 IOR=IOR+1
      IF(NF.EQ.6)GO TO 174
      GO TO 85
  174 NITER=NITER+1
      IF(NITER.GT.4)NITER=4
      ZN=1.0/FLOAT(NITER)
      C=CFCTR(RN,RGSHFT,ICHG)
      DIF=(ISH-IOR)
      CORR=ZN*DIF*(FORKTR*100.0/C)/12.0
      CORR=FDCRCR(CORR,C,BR,R)
      RGSHFT=RGSHFT+CORR
      RANGE=RANGE+CORR
      NF=0
      ISH=0
      IOR=0
      GO TO 85
   88 NTGT=NTGT+1
C
C
C     THE SIMULATED MISSION IS COMPLETE.TALLIES OF REGIS-
C     TRATION ERRORS, ROUND EXPENDITURES, TARGET HITS AND
C     INVALID REGISTRATIONS ARE RECORDED FOR STATISTICAL
C     ANALYSIS
C
   58 CHECK=DEFLEC
      ADJCI=RANGE
      NCTRGT=NCTRGT+NTGT
      NRDS=N+J
      MISDIS=SQRT(ADJCI**2+CHECK**2)
C
      DTSQ=DTSQ+MISDIS**2
      MISTOT=MISTOT+MISDIS
      RGMISS=RGMISS+ADJCI
      RMIS=RMIS+ABS(ADJCI)
      RGSQ=RGSQ+ADJCI**2
      DFMISS=DFMISS+CHECK
      DMIS=DMIS+ABS(CHECK)
      DFSQ=DFSQ+CHECK**2
```

```
      IRDS=IRDS+NRDS
      RDSQ=RDSQ+NRDS**2
      JRDS=JRDS+N
      JSQ=JSQ+N**2
      FFERG1=FFERG1+ABS(FFERG)
      FFEDF1=FFEDF1+ABS(FFEDF)
      FERGSQ=FERGSQ+(FFERG)**2
      FEDFSQ=FEDFSQ+(FFEDF)**2
      MRE=FFERG*FFERG+FFEDF*FFEDF
      MRE=SQRT(MRE)
      MRE1=MRE1+MRE
      MRSQ=MRSQ+MRE*MRE
      IF(NI-750)200,300,300
  300 AVMISS=MISTCT/FLOAT(NI)
      SDMD=SQRT((DTSQ/FLOAT(NI))-AVMISS*AVMISS)
      WRITE(6,9004)ANGLT,HALFS
      WRITE(6,9100)BR,BD
      WRITE(6,6500)WRG,WDF
      RGAV=FFERG1/FLOAT(NI)
      SDAVR=SQRT((FERGSQ/FLOAT(NI))-RGAV*RGAV)
      WRITE(6,9006)RGAV,SDAVR
      DFAV=FFEDF1/FLOAT(NI)
      SDAVD=SQRT((FEDFSQ/FLOAT(NI))-DFAV*DFAV)
      WRITE(6,9007)DFAV,SDAVD
      AVMRE=MRE1/FLOAT(NI)
      SDMRE=SQRT((MRSQ/FLOAT(NI))-AVMRE*AVMRE)
      WRITE(6,9110)AVMRE,SDMRE
      WRITE(6,9000)AVMISS,SDMD
      AVRGER=RGMISS/FLOAT(NI)
      SDRG=SQRT((RGSQ/FLOAT(NI))-AVRGER*AVRGER)
      WRITE(6,9001)AVRGER,SDRG
      AVDFER=DFMISS/FLOAT(NI)
      SDDF=SQRT((DFSQ/FLOAT(NI))-AVDFER*AVDFER)
      WRITE(6,9002)AVDFER,SDDF
      RAV=RMIS/FLOAT(NI)
      DAV=DMIS/FLOAT(NI)
      WRITE(6,5200)RAV,DAV
      AVRDS=IRDS/FLOAT(NI)
      SDRD=SQRT((RDSQ/FLOAT(NI))-AVRDS*AVRDS)
      WRITE(6,9003)AVRDS,SDRD
      AVJRDS=JRDS/FLOAT(NI)
      SDJR=SQRT((JSQ/FLOAT(NI))-AVJRDS*AVJRDS)
      WRITE(6,9005)AVJRDS,SDJR
      WRITE(6,9900)NOGOOD
      WRITE(6,9990)NOTRGT
      IF(IDO)500,501,503
 9011 FORMAT('1',T7,'RANGE=',F9.2,7X,'PER=',F6.2,7X,'PED=',F
     16.2)
 9004 FORMAT('0',T7,'ANGLE T=',F9.2,T60,'HALF S=',F6.2)
 6500 FORMAT(' ',T7,'PERCENT RANGE ERROR=',F9.3,5X,'PERCENT
     1DEVIATION ERROR=',F9.3)
 9006 FORMAT(' ',T7,'ABS AV FFE RG=',F9.2,T60,'STD DEV=',F6.
     12)
 9007 FORMAT(' ',T7,'ABS AV FFE DF=',F9.2,T60,'STD DEV=',F6.
     12)
 9110 FORMAT(' ',T7,'FFE MRE=',F6.2,T60,'STD DEV MRE=',F6.2)
 9000 FORMAT(' ',T7,'AVERAGE MISS DISTANCE=',F9.2,T60,'STD D
     1EV=',F9.2)
 9001 FORMAT(' ',T7,'ABS AV RANGE ERROR=',F9.2,T60,'STD DEV=
     1',F9.2)
 9002 FORMAT(' ',T7,'ABS DEF ERROR=',F9.2,T60,'STD DEV=',F9.
     12)
 9003 FORMAT(' ',T7,'AVE RDS FIRED=',F6.2,T60,'STD DEV=',F6.
     12)
 9005 FORMAT(' ',T7,'AV FFE ROUNDS=',F6.2,T60,'STD DEV=',F6.
     12)
 9900 FORMAT(' ',T7,'TOTAL IINVALID REGISTRATIONS=',I6)
 9100 FORMAT('0',T7,'STD DEV GUN QE ERROR=',F6.2,T60,'STD DE
     1V OF GUN ERROR=',F6.2)
 5200 FORMAT(' ',T7,'ABSRANGE MISS=',F9.2,T60,'ABSDEVIATION
     1MISS=',F9.2)
 9990 FORMAT(' ',T7,'TOTAL TARGETS STRUCK=',I6)
```

```
503 STOP
    END
```

```
C     PROGRAM LISTING OF ROBBINS-MONRO TYPE PRECISION FIRE
C     PROCEDURE
C
C
C     USER INFORMATION.
C
C     THE PROGRAM AS WRITTEN WILL INVESTIGATE ONLY THE
C     FOLLOWING AMMUNITION PARAMETER INPUTS EXTRACTED FROM
C     FIRING TABLES TFT 155-AH-2
C
C     CHARGE     RANGE(RN)   ICHG    PER    PED
C      5GB         2000       59       7      1
C      5WB         5500       51      20      3
C      5GB         6000        5      13      3
C      6           8000        6      27      4
C      6          10000       61      34      5
C
C     FOR OTHER PARAMETER VALUES THE USER MUST MAKE APPRO-
C     PRIATE CHANGES TO FORKF, FORKT, AND OFCTR ROUTINES
C
C     THE USER MUST SPECIFY THE FOLLOWING INPUT PARAMETERS:
C
C     A-      THE TARGET SEMIMAJOR AXIS IN METERS
C     B-      THE TARGET SEMIMINOR AXIS IN METERS
C     TGTANG- THE TARGET ORIENTING ANGLE IN MILS
C     MTGT-   SET MTGT=0 IF REGISTRATION DESIRED
C     ISPEC-  SPECIFY THE NUMBER OF POSITIVE RANGE SPOTS AT
C             EACH ELEVATION SETTING DESIRED.FOR THE
C             RECOMMENDED PROCEDURE SET ISPEC=1
C     NROUND- SPECIFY THE NUMBER OF GROUPS OF POSITIVE SPOT
C             ROUNDS DESIRED UP TO 10
C             SET MTGT=1 IF DESTRUCTION DESIRED
C     ADP-    SET ADP=1 TO SIMULATE FIRE DIRECTION CENTER
C             RANGE CORRECTIONS TO NEAREST 10 METERS
C     ANGLT-  SPECIFY THE ANGLE T TO BE INVESTIGATED IN MILS
C     HALFS-  INSERT THE APPROPRIATE HALFS VALUE SPECIFIED
C             FOR ANGLE T
C     FOANER- SPECIFY THE STANDARD DEVIATION OF OBSERVER
C             ANGLE T ERROR IN MILS
C     YRG-    SPECIFY PROBABILITY OF OBSERVER RANGE SPOT
C             ERROR IN ADJUSTMENT PHASE
C     YDF-    SET PROBABILITY OF OBSERVER DEFLECTION SPOT
C             ERROR IN ADJUSTMENT PHASE
C     WRG-    SPECIFY PROBABILITY OF OBSERVER RANGE SPOT
C             ERROR IN FIRE FOR EFFECT PHASE
C     WDF-    SET PROBABILITY OF OBSERVER DEFLECTION SPOT
C             ERROR IN FIRE FOR EFFECT PHASE
C     ZRG,ZDF-SET TO -1.0 IF OBSERVER SPOT ERROR PROBABILI-
C             TIES ARE TO BE APPLIED;+1.0  IF NO OBSERVER
C             SPOT ERROR IS DESIRED
C     BR,BD-  DUMMY VARIABLES WHICH MUST BE SET TO 0.0
C     OTRG-   THE OBSERVER TARGET RANGE
C     ICHG-   THE POWDER TYPE AND CHARGE
C     RN-     THE RANGE IN METERS TO GO WITH ICHG
C     PER-    APPROPRIATE PROBABLE ERROR IN RANGE CORRES-
C             PONDING TO ICHG
C     PED-    APPROPRIATE PROBABLE ERROR IN DEFLECTION CORR-
C             ESPONDING TO ICHG
C
      REAL MRE1,MRSQ,MRE,MISDIS,OTRG,MISTOT
      LOGICAL LESS
      DIMENSION ADJCI(10),CHECK(10),NOTRGT(10),NRDS(10),NRFR
     1D(10),MISDIS(10),DTSQ(10),MISTOT(10),RGMISS(10),ARMIS(
     110),RGSQ(10),DFMISS(10),AFMIS(10),DFSQ(10),IRDS(10),RD
     1SQ(10),JRDS(10),JSQ(10),LTGTS(10),AVMISS(10),SDMD(10),
     1AVRGER(10),SDRG(10),AVDFER(10),SDDF(10),AVRDS(10),SDRD
     1(10),SDJR(10),RM(10),DM(10),AVJRDS(10),PCS(50),FDDFS1(
     150)
      COMMON TABLEA(50,3),KA,KF,ADD,RN,DEFLEC,IGOOD,ONE,TWO,
     1FOUR,FIVE,EIGHT,SIXTEN,NODEF,IOPP
      IDO=-2
C
```

```
C       MISSION TYPE IS SPECIFIED
C
        MTGT=0
        ADP=1.0
        NROUND=10
        ISPEC=1
C
C       THE AMMUNITION PARAMETERS TO BE INVESTIGATED ARE SET
C
        ICHG=51
        RN=5500.0
        PER=20.0
        PED=3.0
C
C       ANGLE T AND APPROPRIATE HALFS IS SPECIFIED
C
        ANGLT=10.0
        HALFS=2.0
        GO TO 502
    500 CONTINUE
        ANGLT=800.0
        HALFS=4.0
        GO TO 502
    501 CONTINUE
        ANGLT=1600.0
        HALFS=8.0
    502 TWOPI=6.283184
        IDO=IDO+1
C
C       TARGET PARAMTERS ARE SPECIFIED
C
        A=5.0
        B=5.0
        TGTANG=0.0
        THETA1=(TGTANG/6400.0)*TWOPI
        ST1=SIN(THETA1)
        CT1=COS(THETA1)
C
C       COUNTERS AND VECTOR ARRAYS FOR ALL MISSIONS ARE ZEROED
C
        DO 854 I=1,10
        AVRGER(I)=0.0
        DTSQ(I)=0.0
        MISTOT(I)=0.0
        RGMISS(I)=0.0
        ARMIS(I)=0.0
        RGSQ(I)=0.0
        DFMISS(I)=0.0
        AFMIS(I)=0.0
        DFSQ(I)=0.0
        IRDS(I)=0
        RDSQ(I)=0.0
        JRDS(I)=0
        JSQ(I)=0
        LTGTS(I)=0
        AVMISS(I)=0.0
        SDMD(I)=0.0
        SDRG(I)=0.0
        AVDFER(I)=0.0
        SDDF(I)=0.0
        AVRDS(I)=0.0
        SDRD(I)=0.0
        AVJRDS(I)=0.0
        SDJR(I)=0.0
        RM(I)=0.0
        DM(I)=0.0
    854 CONTINUE
        MRE1=0.0
        MRSQ=0.0
        FFERG1=0.0
        FFEDF1=0.0
        FERGSQ=0.0
```

```
      FEDFSQ=0.0
C
C
C     OBSERVER TARGET DISTANCE IS SET
C
      CTRG=2500
C
C     THETA IS CONVERSION OF ANGLE T FROM MILS TO RADIANS.
C
      THETA=(ANGLT/6400.0)*TWOPI
      ST=SIN(THETA)
      CT=COS(THETA)
C
C     THE RANDOM NUMBER GENERATOR IS INITIALIZED.
C
      START=RAN(-351)
C
C     PARAMETER TEST IS USED TO DETERMINE WHEN TO ENTER INTO
C     FIRE FOR EFFECT PHASE.
C
      TEST1=100.0
      TEST=50.0
      IF(PER.GT.38.0)TEST=100
      NI=0
  200 NI=NI+1
C
C     THE OBSERVER SPOT ERROR PARAMTERS ARE SPECIFIED
C
      YRG=0.0
      YDF=0.0
      WRG=0.0
      WDF=0.0
      ZRG=1.0
      ZDF=1.0
      BR=0.0
      BD=0.0
C
C     THE OBSERVER ANGLE T ERROR IS APPLIED TO DETERMINE THE
C     TRUE ANGLE T
C
      FCANER=0.0
      ANGFO=ANGLT+(RAN(0))*FCANER
      TETAFO=(ANGFO/6400.0)*TWOPI
      STFO=SIN(TETAFO)
      CTFO=COS(TETAFO)
C
C     THE INITIAL BURST LOCATION AT START OF EACH MISSION IS
C     ESTABLISHED. IT IS ASUMED THAT THE INITIAL ROUND WILL
C     BE UNIFORMLY DISTRIBUTED IN AN 800 BY 400 METER RECT-
C     ANGLE CENTERED ON THE TRUE TARGET CENTER
C
      RANGE=RAN(1)*400.0
      IF(RAN(1).LT..5)RANGE=-RANGE
      DEFLEC=RAN(1)*200.0
      IF(RAN(1).LT..5)DEFLEC=-DEFLEC
C
C     COUNTERS AND VARIABLES FOR EACH MISSION ARE ZEROED
C
      DO 853 I=1,10
      ADJCI(I)=0.0
      CHECK(I)=0.0
      NCTRGT(I)=0
      NRDS(I)=0
      NRFRD(I)=0
      MISDIS(I)=0.0
  853 CONTINUE
      DO 99 I=1,50
      PCS(I)=0
      FDDFS1(I)=0
   99 CONTINUE
      DO 400 IM=1,50
      DO 400 MM=1,3
```

```
400 TABLEA(IM,MM)=0.0
    SHIFT=0.0
    FOCOR=0.0
    FODFCR=0.0
    RGSHFT=0.0
    ICR=0
    ISH=0
    DEFTRY=0.0
    IDOUT=0
    IGOOD=0
    N=0
    KA=0
    KF=0
    J=0
    JJ=0
    NTGT=0
    NITER=0
    IONE=0
    ACD=HALFS*RN*0.001
    CHK=RN*0.001
    ONE=CHK
    TWO=CHK*2.0
    FOUR=CHK*4.0
    FIVE=CHK*5.0
    EIGHT=CHK*8.0
    SIXTEN=CHK*16.0
    R=1.0
    ISHIFT=1000
C
C   THE ADJUSTMENT PHASE IS ENTERED
C
C
C   THE OBSERVER CORRECTIONS ARE TRANSFERED TO THE GUN
C   TARGET COORDINATE SYSTEM
C
  1 SHFTDF=ROTGND(FOCOR,SHIFT,ST,CT)
    SHFTRG=ROTGNR(FOCOR,SHIFT,ST,CT)
    IF(ADP.GT.0.0)SHFTRG=RDOFF(SHFTRG)
C
C   THE C-FACTOR IS COMPUTED
C
    C=CFCTR(RN,RGSHFT,ICHG)
C
C   TOTAL RANGE CORRECTIONS ARE COMPUTED
C
    RGSHFT=RGSHFT+SHFTRG
C
C   RANGE AND DEFLECTION CORRECTIONS ARE APPLIED;THE AIM
C   POINT CORRESPONDING TO ELEVATION AND DEFLECTION COR-
C   RECTIONS IS COMPUTED
C
    RANGE=RANGE+FDCRCR(SHFTRG,C,BR,R)
    DEFLEC=DEFLEC+FDCDCR(RN,RANGE,SHFTDF,BD)
C
C   OBSERVER SPOT ERROR IS CHANGED FROM ADJUSTMENT ERROR
C   TO FIRE FOR EFFECT ERROR.IT IS ASSUMED THAT THE PRO-
C   BABILITY OF OBSERVER SPOT ERROR WILL BE GREATER IN THE
C   FIRE FOR EFFECT PHASE
C
    IF(IABS(ISHIFT).LE.TEST1)WRG=YRG
    IF(IABS(ISHIFT).LE.TEST1)WDF=YDF
C
C   DETERMINATION TO ENTER THE FIRE FOR EFFECT PHASE IS
C   MADE
C
    IF(IABS(ISHIFT).LE.TEST)GO TO 101
    J=J+1
C
C   ACTUAL BURST LOCATION IN GUN-TARGET COORDINATE SYS-
C   TEM IS COMPUTED
C
    RG=(RAN(0))*PER/.6745+RANGE
```

```
      DF=(RAN(0))*PED/.6745+DEFLEC
C
C     ACTUAL BURST IMPACT LOCATION IN THE TARGET COORDINATE
C     SYSTEM IS ESTABLISHED
C
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
C
C     THE BURST IMPACT AS THE OBSERVER SEES IT IN THE OBSER-
C     VER COORDINATE SYSTEM IS COMPUTED
C
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(J.GT.1)GO TO 64
C
C     THE OBSERVER DETERMINES THE INITIAL RANGE SHIFT TO USE
C     IN THE ADJUSTMENT PHASE
C
      BURST=RDOFF(ERRFCN(CTRG,FORG))
      ISHIFT=ISHFTS(ABS(BURST))
C
C     A DETERMINATION OF TARGET HIT IS MADE
C
   64 IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)IONE=1
      IF(IONE.EQ.1)GO TO 101
C
C     OBSERVER DETERMINES DEVIATION CORRECTIONS
C
      FOCOR=-RDOFF(ERRDF(CTRG,FODF))
C
C     OBSERVER DETERMINES RANGE SPOT OF BURST
C
      FORG1=DBTSNS(FORG,FODF,ZRG,WRG)
      IF(FOCOR)2,3,2
C
C     IF DEVIATION CORRECTION IS GREATER THAN 100 METERS,
C     THE OBSERVER REQUESTS ONLY A DEVIATION SHIFT
C
    2 IF(ABS(FOCOR).GT.100.0)SHIFT=0.0
      IF(ABS(FOCOR).GT.100.0)GO TO 1
      GO TO 4
C
C     OBSERVER SPOTS A LINE BURST.FIRE DIRECTION CENTER
C     DEFLECTION AND DEFLECTION SPOT ARE RECORDED FOR FUTURE
C     REFERENCE FOR DETERMINING CORRECT DEFLECTION IN FIRE
C     FOR EFFECT PHASE
C
    3 KA=KA+1
      KF=KF+1
      TABLEA(KF,2)=DEFSNS(ANGLT,FORG1,FOCOR)
      TABLEA(KF,3)=DEFLEC
    4 IF(FORG1)7,6,7
    6 SHIFT=0.0
C
C     IF TWO OR MORE OBSERVER POSITIVE RANGE ROUNDS HAVE
C     BEEN OBSERVED AND DEVIATION CORRECTION IS LESS THAN
C     50 METERS, FIRE FOR EFFECT PHASE IS ENTERED.
C
      IF(JJ.GT.1.AND.ABS(FOCOR).LT.50.0)ISHIFT=TEST
      GO TO 1
    7 JJ=JJ+1
      POS(JJ)=FORG1
      IF(JJ.GT.1)GO TO 8
      GO TO 9
C
C     OBSERVER DETERMINES IF A RANGE BRACKET EXISTS
C
    8 IF(POS(JJ).GT.0.0.AND.POS(JJ-1).GT.0.0.OR.POS(JJ).LT.0
     1.0.AND.POS(JJ-1).LT.0.0)GO TO 9
C
C     THE RANGE BRACKET IS HALVED
C
```

```
      ISHIFT=ISHIFT*0.5
    9 IF(POS(JJ).GT.0.0)GO TO 60
      SHIFT=FLOAT(ISHIFT)
      GO TO 1
   60 SHIFT=-FLOAT(ISHIFT)
      GO TO 1
C
C     THE FIRE FOR EFFECT PHASE IS ENTERED
C
  101 FFERG=RG
      FFEDF=DF
      WRG=YRG
      WDF=YDF
C
C     THE FIRE FOR EFFECT FORK VALUE TO THE NEAREST MIL IS
C     COMPUTED
C
      FORKTR=FORKT(RN,RGSHFT,ICHG)
      R=-1.0
C
C     THE INITIAL FRACTIONAL FORK RANGE SHIFT IS COMPUTED
C     BASED ON PER
C
C
      ZIL=1.0
      IF(PER.GT.9.0)ZIL=2.0
      IF(PER.GT.18.0)ZIL=3.0
      ZN=1.0/ZIL
      IF(IONE.EQ.1)GO TO 28
   10 N=N+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 28
C
C     OBSERVER SPOTS PRIMARY QUADRANT LOCATION OF BURST
C
      FORGS=DETSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
C
C     OBSERVER SPOTS ARE CONVERTED TO FIRE DIRECTION CENTER
C     SPOTS
C
C
      FDRGS=RNGSNS(ANGLT,FORGS,FODFS)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(IGOOD.EQ.1)GO TO 15
      IF(FDDFS.EQ.0.0)GO TO 15
C
C     DEFLECTION CORRECTIONS ARE DETERMINED BY SUBROUTINE
C     DEFCHK
C
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
      CALL DEFCHK
C
C     APPROPRIATE FORK/ZIL RANGE SHIFT IS APPLIED TO ESTAB-
C     LISH THE INITIAL FIRE FOR EFFECT RANGE BRACKET
C
   15 IF(FDRGS)11,12,13
   11 LESS=.TRUE.
      C=CFCTR(RN,RGSHFT,ICHG)
      SHFTRG=ZN*(FORKTR*100.0/C)
      SHFTRG=FDCRCR(SHFTRG,C,BR,R)
      RGSHFT=RGSHFT+SHFTRG
      RANGE=RANGE+SHFTRG
      GO TO 14
   12 IDCUT=IDCUT+1
      GO TO 10
```

```
   13 LESS=.FALSE.
      C=CFCTR(RN,RGSHFT,ICHG)
      SHFTRG=-ZN*(FORKTR*100.0/C)
      SHFTRG=FOCRCR(SHFTRG,C,BR,R)
      RGSHFT=RGSHFT+SHFTRG
      RANGE=RANGE+SHFTRG
C
C     FIRING TO ESTABLISH THE INITIAL RANGE BRACKET IS CON-
C     DUCTED
C
   14 N=N+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 28
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
      FDRGS=RNGSNS(ANGLT,FORGS,FODFS)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(IGOOD.EQ.1)GO TO 54
      IF(FDDFS.EQ.0.0)GO TO 54
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
      CALL DEFCHK
      IF(FDRGS.EQ.0.0)GO TO 14
C
C     EXISTENCE OF THE INITIAL RANGE BRACKET IS DETERMINED
C
   54 IF(FDRGS.LT.0.0.AND.LESS.OR.FDRGS.GT.0.0.AND..NOT.
     1LESS)GO TO 15
      NF=ISPEC
      GO TO 170
   28 CONTINUE
C
C     A TARGET HIT WAS ATTAINED IN EITHER THE ADJUSTMENT OR
C     INITIAL BRACKET PHASE; THIS NEGATES REQUIREMENT TO ES-
C     TABLISH THE INITIAL RANGE BRACKET
C
      IF(N.EQ.0)J=J-1
      IF(N.EQ.0)N=1
      NF=ISPEC
      GO TO 88
   86 NF=0
C
C     FIRING AFTER INITIAL RANGE BRACKET ACHIEVEMENT IS CON-
C     TINUED UNTIL THE DESIRED NUMBER OF POSITIVE RANGE SPOT
C     ROUNDS TO COMPLETE THE REGISTRATION HAVE BEEN FIRED.
C     IN THIS PHASE A RANGE CORRECTION IS MADE AFTER EACH
C     FIRE DIRECTION CENTER POSITIVE RANGE SPOT
C
   85 N=N+1
      NF=NF+1
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 88
      FORGS=DBTSNS(FORG,FODF,ZRG,WRG)
      FODFS=LNSNS(FODF,ZDF,WDF)
      FDRGS=RNGSNS(ANGLT,FORGS,FODFS)
      FDDFS=DEFSNS(ANGLT,FORGS,FODFS)
      IF(FDDFS.EQ.0.0)GO TO 170
      IF(IGOOD.EQ.1)GO TO 175
      KF=KF+1
      TABLEA(KF,2)=FDDFS
      TABLEA(KF,3)=DEFLEC
```

```
      CALL DEFCHK
      GO TO 170
   88 NTGT=NTGT+1
      IF(MTGT.EQ.1)GO TO 58
      IOR=IOR+1
      ISH=ISH+1
      IGOOD=1
      ZIL=ZIL+1.0
      IF(NF.EQ.ISPEC)GO TO 174
      GO TO 85
C
C     DEFLECTION CORRECTIONS ARE APPLIED
C
  175 APPLDF=ONE
      IF(FDDFS.GT.0.0)GO TO 176
      DEFLEC=DEFLEC+APPLDF
      GO TO 170
  176 DEFLEC=DEFLEC-APPLDF
  170 IF(FDRGS)171,172,173
  172 NF=NF-1
      GO TO 85
  171 ISH=ISH+1
      ZIL=ZIL+1.0
      IF(NF.EQ.ISPEC)GO TO 174
      GO TO 85
  173 IOR=IOR+1
      ZIL=ZIL+1.0
      IF(NF.EQ.ISPEC)GO TO 174
      GO TO 85
C
C     RANGE CORRECTIONS ARE COMPUTED AND APPLIED
C
  174 NITER=NITER+1
      C=CFCTR(RN,RGSHFT,ICHG)
      ZN=1.0/ZIL
      DIF=(ISH-IOR)
      CORR=ZN*DIF*(FORKTR*100.0/C)
      CORR=FDCRCR(CORR,C,BR,R)
      RGSHFT=RGSHFT+CORR
      RANGE=RANGE+CORR
      ADJCI(NITER)=RANGE
      CHECK(NITER)=DEFLEC
      NOTRGT(NITER)=NTGT
      NRDS(NITER)=N+J
      NRFRD(NITER)=N
      MISDIS(NITER)=SQRT(ADJCI(NITER)*ADJCI(NITER)+CHECK(NIT
     1ER)*CHECK(NITER))
C
C     IF THE SPECIFIED NUMBER OF ROUNDS HAVE BEEN FIRED,THE
C     REGISTRATION IS COMPLETE. IF TARGET DESTRUCTION DATA
C     IS DESIRED, FIRING IS CONTINUED UNTIL A TARGET HIT IS
C    .ATTAINED.
C
      IF(NROUND.EQ.NITER.AND.MTGT.EQ.0)GO TO 58
      NF=0
      ISH=0
      IOR=0
      GO TO 85
   58 CONTINUE
C
C     THE SIMULATED MISSION IS COMPLETE.TALLIES OF REGIS-
C     TRATION ERRORS,TARGET HITS, AND ROUND EXPENDITURES ARE
C     RECORDED FOR STATISTICAL ANALYSIS
C
      DO 800 I=1,NITER
      DTSQ(I)=DTSQ(I)+MISDIS(I)*MISDIS(I)
      MISTOT(I)=MISTOT(I)+MISDIS(I)
      RGMISS(I)=RGMISS(I)+ADJCI(I)
      ARMIS(I)=ARMIS(I)+ABS(ADJCI(I))
      RGSQ(I)=RGSQ(I)+ADJCI(I)*ADJCI(I)
      DFMISS(I)=DFMISS(I)+CHECK(I)
      AFMIS(I)=AFMIS(I)+ABS(CHECK(I))
```

```
      DFSQ(I)=DFSQ(I)+CHECK(I)*CHECK(I)
      IRDS(I)=IRDS(I)+NRDS(I)
      RDSQ(I)=RDSQ(I)+NRDS(I)*NRDS(I)
      JRDS(I)=JRDS(I)+NRFRD(I)
      JSQ(I)=JSQ(I)+NRFRD(I)*NRFRD(I)
      LTGTS(I)=LTGTS(I)+NOTRGT(I)
  800 CONTINUE
      FFERG1=FFERG1+ABS(FFERG)
      FFEDF1=FFEDF1+ABS(FFEDF)
      FERGSQ=FERGSQ+(FFERG)**2
      FEDFSQ=FEDFSQ+(FFEDF)**2
      MRE=FFERG*FFERG+FFEDF*FFEDF
      MRE=SQRT(MRE)
      MRE1=MRE1+MRE
      MRSQ=MRSQ+MRE*MRE
      IF(NI-750)200,300,300
  300 ZIP=FLOAT(NI)
      WRITE(6,9011)RN,PER,PED
      WRITE(6,9004)ANGLT,HALFS
      WRITE(6,1000)WRG,WDF
      RGAV=FFERG1/FLOAT(NI)
      SDAVR=SQRT((FERGSQ/FLOAT(NI))-RGAV*RGAV)
      WRITE(6,9006)RGAV,SDAVR
      DFAV=FFEDF1/FLOAT(NI)
      SDAVD=SQRT((FEDFSQ/FLOAT(NI))-DFAV*DFAV)
      WRITE(6,9007)DFAV,SDAVD
      AVMRE=MRE1/FLOAT(NI)
      SDMRE=SQRT((MRSQ/FLOAT(NI))-AVMRE*AVMRE)
      WRITE(6,9110)AVMRE,SDMRE
      DO 801 I=1,NITER
      AVMISS(I)=MISTOT(I)/ZIP
      SDMD(I)=SQRT((DTSQ(I)/ZIP)-AVMISS(I)*AVMISS(I))
      WRITE(6,9907)I
      WRITE(6,9000)AVMISS(I),SDMD(I)
      AVRGER(I)=RGMISS(I)/ZIP
      SDRG(I)=SQRT((RGSQ(I)/ZIP)-AVRGER(I)*AVRGER(I))
      WRITE(6,9001)AVRGER(I),SDRG(I)
      AVDFER(I)=DFMISS(I)/ZIP
      SDDF(I)=SQRT((DFSQ(I)/ZIP)-AVDFER(I)*AVDFER(I))
      WRITE(6,9002)AVDFER(I),SDDF(I)
      RM(I)=ARMIS(I)/ZIP
      DM(I)=AFMIS(I)/ZIP
      WRITE(6,9906)RM(I),DM(I)
      AVRDS(I)=IRDS(I)/ZIP
      SDRD(I)=SQRT((RDSQ(I)/ZIP)-AVRDS(I)*AVRDS(I))
      WRITE(6,9003)AVRDS(I),SDRD(I)
      AVJRDS(I)=JRDS(I)/ZIP
      SDJR(I)=SQRT((JSQ(I)/ZIP)-AVJRDS(I)*AVJRDS(I))
      WRITE(6,9005)AVJRDS(I),SDJR(I)
      WRITE(6,9900)LTGTS(I)
  801 CONTINUE
      IF(IDO)500,501,503
 1000 FORMAT(' ',T7,'P RANGE ERROR=',F9.2,T60,'P DEVIATION E
     1RROR=',F9.2)
 9011 FORMAT('1',T7,'RANGE=',F9.2,7X,'PER=',F6.2,7X,'PED=',F
     16.2)
 7000 FORMAT(' ',T7,'ROUND NUMBER=',I4,10X,'AIM POINT RANGE=
     1',F9.3,10X,'AIM POINT DEVIATION=',F9.3)
 9004 FORMAT('0',T7,'ANGLE T=',F9.2,T60,'HALFS=',F6.2)
 9006 FORMAT(' ',T7,'ABS AV FFE RG=',F9.2,T60,'STD DEV=',F6.
     12)
 9007 FORMAT(' ',T7,'ABS AV FFE DF=',F9.2,T60,'STD DEV=',F6.
     12)
 9110 FORMAT(' ',T7,'FFE MRE=',F6.2,T60,'STD DEV MRE=',F6.2)
 9000 FORMAT('0',T7,'AVERAGE MISS DISTANCE=',F9.2,T60,'STD D
     1DEV=',F9.2)
 9001 FORMAT(' ',T7,'AVERAGE RANGE ERROR=',F9.2,T60,'STD DEV
     1=',F9.2)
 9002 FORMAT(' ',T7,'AVERAGE DEFLECTION ERROR=',F9.2,T60,'ST
     1D DEV=',F9.2)
 9003 FORMAT(' ',T7,'AVE RDS FIRED=',F6.2,T60,'STD DEV=',F6.
     12)
```

```
9005 FORMAT(' ',T7,'AV FFE ROUNDS=',F6.2,T60,'STD DEV=',F6.
    12)
9900 FORMAT(' ',T7,'TOTAL TARGETS STRUCK=',I6)
9100 FORMAT('0',T7,'STD DEV GUN QE ERROR=',F6.2,T60,'STD DE
    1V OF GUN ERROR=',F6.2)
9906 FORMAT(' ',T7,'ABSRANGE MISS=',F9.2,T60,'ABSDEVIATION
    1MISS=',F9.2)
9907 FORMAT('0',T45,'FIRE FOR EFFECT ROUND NO:',I4)
 503 STOP
     END
```

```
C     COMMON  FUNCTIONAL ROUTINE LISTING FOR THE FM 6-40 AND
C     THE ROBBINS-MONRO SIMULATION PROGRAMS
C

      FUNCTION DBTSNS(X,Y,Z,W)
C
C     THIS FUNCTION DETERMINES OBSERVER OVER AND SHORT BURST
C     SPOTS.THIS IS OBSERVER ERROR MODEL #1 AS DESCRIBED IN
C     APPENDIX A
C
C     X- OBSERVER RANGE MISS DISTANCE
C
C     Y- OBSERVER DEFLECTION MISS DISTANCE
C
C     Z- INDICATES IF OBSERVER SPOT ERROR IS TO BE APPLIED
C
C     W- PROBABILITY OF OBSERVER OVER-SHORT SPOT ERROR
C
      IF(ABS(X/Y).LT..36397)GO TO 1
      SNS=X
      T=W
      IF(Z.GT.0)GO TO 2
      GO TO 2
    1 SNS=0.0
    2 DBTSNS=SNS
      RETURN
      END

      FUNCTION DBTSNS(X,Y,Z,W)
C
C     THIS FUNCTION DETERMINES OBSERVER OVER AND SHORT BURST
C     SPOTS.THIS IS OBSERVER ERROR MODEL #2 AS DESCRIBED IN
C     APPENDIX A
C
C     X- OBSERVER RANGE MISS DISTANCE
C
C     Y- OBSERVER DEFLECTION MISS DISTANCE
C
C     Z- INDICATES IF OBSERVER SPOT ERROR IS TO BE APPLIED
C
C     W- PROBABILITY OF OBSERVER OVER-SHORT SPOT ERROR
C
C     B- PROBABILITY OF DOUBTFUL SPOT
C
      B=0.3333
      A=RAN(1)
      T=W
      SNS=X
      IF(Z.GT.0)GO TO 2
      IF(ABS(X/Y).GT.1.731)GO TO 3
      IF(A.LT.B)GO TO 1
      IF(A.LT.(B+T))SNS=-SNS
      GO TO 2
    3 T=0.02
      IF(A.LT.T)SNS=-SNS
      GO TO 2
    1 SNS=0.0
    2 DBTSNS=SNS
      RETURN
      END

      FUNCTION ERRDF(X,Y)
C
C     THIS FUNCTION DETERMINES OBSERVER'S ESTIMATE OF ACTUAL
C     DEFLECTION MISS DISTANCE OF IMPACT. THE ESTIMATE IS
C     SUBJECT TO A 5 MIL ERROR UNIFORMLY DISTRIBUTED
C     U(-5MILS,+5MILS)
C
C     X- OBSERVER TARGET RANGE IN METERS
```

```
C
C     Y- ACTUAL DEFLECTION MISS DISTANCE IN METERS
C
      Z=0.005*X
      ERROR=Z*(RAN(1))
      IF(RAN(1).GT..5)GO TO 1
      ERROR=-ERROR
    1 ERDF=Y+ERROR
      IF(ABS(ERDF).LT.5.0)GO TO 2
      ERRDF=ERDF
      GO TO 3
    2 ERRDF=0.0
    3 RETURN
      END


      FUNCTION LNSNS(X,Z,W)
C
C     THIS FUNCTION DETERMINES OBSERVER LEFT,RIGHT, AND LINE
C     BURST SPOTS
C
C     X- OBSERVER DEFLECTION MISS DISTANCE
C
C     Z- INDICATES IF OBSERVER SPOT ERROR IS TO BE APPLIED
C
C     W- PROBABILITY OF OBSERVER LEFT-RIGHT SPOT ERROR
C
      IF(ABS(X).LT.5.0)GO TO 1
      SNS=X
      IF(Z.GT.0)GO TO 2
      IF(RAN(1).LT.W)SNS=-SNS
      GO TO 2
    1 SNS=0.0
    2 LNSNS=SNS
      RETURN
      END


      FUNCTION RNGSNS(X,Y,Z)
C
C     THIS FUNCTION CONVERTS OBSERVER BURST SPOTS INTO FIRE
C     DIRECTION CENTER RANGE SPOTS
C
C     X- THE OBSERVER REPORTED ANGLE T
C
C     Y- OBSERVER RANGE SPOT
C
C     Z- OBSERVER DEFLECTION SPOT
C
C     W- FIRE DIRECTION CENTER RANGE SPOT
C        W= 0.0 IMPLIES DOUBTFUL
C        W= 1.0 IMPLIES OVER
C        W=-1.0 IMPLIES SHORT
C
      IF(X-99.0)1,1,10
    1 IF(Y.EQ.0.AND.Z.GT.0)GO TO 2
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 2
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 3
      IF(Y.GT.0.AND.Z.GT.0)GO TO 3
      IF(Y.GT.0.AND.Z.LT.0)GO TO 3
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 4
      IF(Y.LT.0.AND.Z.GT.0)GO TO 4
      IF(Y.LT.0.AND.Z.LT.0)GO TO 4
    2 W=0
      GO TO 99
    3 W=1.0
      GO TO 99
    4 W=-1.0
      GO TO 99
   10 IF(X-799.0)11,11,20
   11 IF(Y.EQ.0.AND.Z.GT.0)GO TO 12
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 13
```

```
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 12
      IF(Y.GT.0.AND.Z.GT.0)GO TO 12
      IF(Y.GT.0.AND.Z.LT.0)GO TO 12
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 13
      IF(Y.LT.0.AND.Z.GT.0)GO TO 13
      IF(Y.LT.0.AND.Z.LT.0)GO TO 13
   12 W=1.0
      GO TO 99
   13 W=-1.0
      GO TO 99
   20 IF(X-1399.0)21,21,30
   21 IF(Y.EQ.0.AND.Z.GT.0)GO TO 23
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 24
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 23
      IF(Y.GT.0.AND.Z.GT.0)GO TO 23
      IF(Y.GT.0.AND.Z.LT.0)GO TO 22
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 24
      IF(Y.LT.0.AND.Z.GT.0)GO TO 22
      IF(Y.LT.0.AND.Z.LT.0)GO TO 24
   22 W=0
      GO TO 99
   23 W=1.0
      GO TO 99
   24 W=-1.0
      GO TO 99
   30 IF(X-1600.0)31,31,40
   31 IF(Y.EQ.0.AND.Z.GT.0)GO TO 32
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 33
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 32
      IF(Y.GT.0.AND.Z.GT.0)GO TO 32
      IF(Y.GT.0.AND.Z.LT.0)GO TO 33
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 33
      IF(Y.LT.0.AND.Z.GT.0)GO TO 32
      IF(Y.LT.0.AND.Z.LT.0)GO TO 33
   32 W=1.0
      GO TO 99
   33 W=-1.0
      GO TO 99
   40 IF(X-1799.0)41,41,50
   41 IF(Y.EQ.0.AND.Z.GT.0)GO TO 43
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 44
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 44
      IF(Y.GT.0.AND.Z.GT.0)GO TO 43
      IF(Y.GT.0.AND.Z.LT.0)GO TO 44
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 43
      IF(Y.LT.0.AND.Z.GT.0)GO TO 43
      IF(Y.LT.0.AND.Z.LT.0)GO TO 44
   50 IF(X-2399.0)51,51,60
   51 IF(Y.EQ.0.AND.Z.GT.0)GO TO 43
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 44
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 44
      IF(Y.GT.0.AND.Z.GT.0)GO TO 42
      IF(Y.GT.0.AND.Z.LT.0)GO TO 44
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 43
      IF(Y.LT.0.AND.Z.GT.0)GO TO 43
      IF(Y.LT.0.AND.Z.LT.0)GO TO 42
   60 IF(X-3099.0)61,61,70
   61 IF(Y.EQ.0.AND.Z.GT.0)GO TO 43
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 44
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 44
      IF(Y.GT.0.AND.Z.GT.0)GO TO 44
      IF(Y.GT.0.AND.Z.LT.0)GO TO 44
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 43
      IF(Y.LT.0.AND.Z.GT.0)GO TO 43
      IF(Y.LT.0.AND.Z.LT.0)GO TO 43
   70 IF(X-3200.0)71,71,71
   71 IF(Y.EQ.0.AND.Z.GT.0)GO TO 42
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 42
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 44
      IF(Y.GT.0.AND.Z.GT.0)GO TO 44
      IF(Y.GT.0.AND.Z.LT.0)GO TO 44
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 43
```

```
      IF(Y.LT.0.AND.Z.GT.0)GO TO 43
      IF(Y.LT.0.AND.Z.LT.0)GO TO 43
   42 W=0.0
      GO TO 99
   43 W=1.0
      GO TO 99
   44 W=-1.0
   99 RNGSNS=W
      RETURN
      END

      FUNCTION DEFSNS(X,Y,Z)
C
C     THIS FUNCTION CONVERTS OBSERVER BURST SPOTS INTO FIRE
C     DIRECTION CENTER DEFLECTION SPOTS
C
C     X- THE REPORTED ANGLE T
C
C     Y- OBSERVER RANGE SPOT
C
C     Z- OBSERVER DEFLECTION SPOT
C
C     W- FIRE DIRECTION CENTER DEFLECTION SPOT
C        W= 0.0 IMPLIES DOUBTFUL
C        W= 1.0 IMPLIES RIGHT
C        W=-1.0 IMPLIES LEFT
C
      IF(X-99.0)1,1,10
    1 IF(Y.EQ.0.AND.Z.GT.0)GO TO 2
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 3
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 3
      IF(Y.GT.0.AND.Z.GT.0)GO TO 2
      IF(Y.GT.0.AND.Z.LT.0)GO TO 3
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 2
      IF(Y.LT.0.AND.Z.GT.0)GO TO 2
      IF(Y.LT.0.AND.Z.LT.0)GO TO 3
    2 W=1.0
      GO TO 99
    3 W=-1.0
      GO TO 99
   10 IF(X-499.0)11,11,20
   11 IF(Y.EQ.0.AND.Z.GT.0)GO TO 13
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 14
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 14
      IF(Y.GT.0.AND.Z.GT.0)GO TO 12
      IF(Y.GT.0.AND.Z.LT.0)GO TO 14
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 13
      IF(Y.LT.0.AND.Z.GT.0)GO TO 13
      IF(Y.LT.0.AND.Z.LT.0)GO TO 12
   12 W=0
      GO TO 99
   13 W=1.0
      GO TO 99
   14 W=-1.0
      GO TO 99
   20 IF(X-1399.0)21,21,40
   21 IF(Y.EQ.0.AND.Z.GT.0)GO TO 22
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 22
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 24
      IF(Y.GT.0.AND.Z.GT.0)GO TO 22
      IF(Y.GT.0.AND.Z.LT.0)GO TO 24
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 23
      IF(Y.LT.0.AND.Z.GT.0)GO TO 23
      IF(Y.LT.0.AND.Z.LT.0)GO TO 22
   22 W=0
      GO TO 99
   23 W=1.0
      GO TO 99
   24 W=-1.0
      GO TO 99
   40 IF(X-1799.0)41,41,50
```

```
   41 IF(Y.EQ.0.AND.Z.GT.0)GO TO 42
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 42
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 44
      IF(Y.GT.0.AND.Z.GT.0)GO TO 44
      IF(Y.GT.0.AND.Z.LT.0)GO TO 44
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 43
      IF(Y.LT.0.AND.Z.GT.0)GO TO 43
      IF(Y.LT.0.AND.Z.LT.0)GO TO 43
   50 IF(X-2699.0)51,51,60
   51 IF(Y.EQ.0.AND.Z.GT.0)GO TO 42
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 42
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 44
      IF(Y.GT.0.AND.Z.GT.0)GO TO 44
      IF(Y.GT.0.AND.Z.LT.0)GO TO 42
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 43
      IF(Y.LT.0.AND.Z.GT.0)GO TO 42
      IF(Y.LT.0.AND.Z.LT.0)GO TO 43
   60 IF(X-3099.0)61,61,70
   61 IF(Y.EQ.0.AND.Z.GT.0)GO TO 44
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 43
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 44
      IF(Y.GT.0.AND.Z.GT.0)GO TO 44
      IF(Y.GT.0.AND.Z.LT.0)GO TO 42
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 43
      IF(Y.LT.0.AND.Z.GT.0)GO TO 42
      IF(Y.LT.0.AND.Z.LT.0)GO TO 43
   70 IF(X-3200.0)71,71,71
   71 IF(Y.EQ.0.AND.Z.GT.0)GO TO 44
      IF(Y.EQ.0.AND.Z.LT.0)GO TO 43
      IF(Y.GT.0.AND.Z.EQ.0)GO TO 44
      IF(Y.GT.0.AND.Z.GT.0)GO TO 44
      IF(Y.GT.0.AND.Z.LT.0)GO TO 43
      IF(Y.LT.0.AND.Z.EQ.0)GO TO 43
      IF(Y.LT.0.AND.Z.GT.0)GO TO 44
      IF(Y.LT.0.AND.Z.LT.0)GO TO 43
   42 W=0
      GO TO 99
   43 W=1.0
      GO TO 99
   44 W=-1.0
   99 DEFSNS=W
      RETURN
      END

      FUNCTION ISHFTS(X)
C
C     THIS FUNCTION DETERMINES THE OBSERVER'S INITIAL RANGE
C     SHIFT IN ADJUSTMENT PHASE
C
C     X- OBSERVER ESTIMATE OF RANGE MISS DISTANCE OF FIRST
C        ROUND
C
      IF(X-100.0)1,1,2
    1 ISHOOT=200
      GO TO 5
    2 IF(X-200.0)3,3,4
    3 ISHOOT=400
      GO TO 5
    4 IF(X.GT.200.0)ISHOOT=800
    5 ISHFTS=ISHOOT
      RETURN
      END

      FUNCTION ERRFCN(X,Y)
C
C     THIS FUNCTION DETERMINES OBSERVER'S ESTIMATE OF ACTUAL
C     RANGE MISS DISTANCE OF IMPACT.THE ESTIMATE IS SUBJECT
C     TO AN ERROR UNIFORMLY DISTRIBUTED U(-ACTUAL MISS DIS-
C     TANCE,+ACTUAL MISS DISTANCE)
C
```

```
C       Y- ACTUAL IMPACT MISS DISTANCE
C
C       X- OBSERVER TARGET RANGE IN METERS
C
        ERROR=(X/2500.0)*ABS(Y)*(RAN(1))
        IF (RAN(1).GT..5)GO TO 1
        ERROR=-ERROR
      1 ERRG=Y+ERROR
        IF(Y.LT.0..AND.ERRG.GT.0.OR.Y.GT.0.AND.ERRG.LT.0)GO TO
        ERRFCN=ERRG
        GO TO 3
      2 ERRFCN=0.0
      3 RETURN
        END


        SUBROUTINE DEFCHK
C
C       THIS SUBROUTINE DETERMINES APPROPRIATE DEFLECTION
C       CORRECTIONS IN FIRE FOR EFFECT PHASE AND  IF THE AD-
C       JUSTED DEFLECTION HAS BEEN ACHIEVED.ALL POSITIVE FIRE
C       DIRECTION CENTER DEFLECTION SPOTS ARE COMPARED WITH
C       MOST CURRENT SPOT TO DETERMINE APPROPRIATE ACTION
C
        DIMENSION STORE(50)
        COMMON TABLEA(50,3),KA,KF,ADD,RN,DEFLEC,IGOOD,ONE,TWO,
       1FOUR,FIVE,EIGHT,SIXTEN,NODEF,IOPP
        IF(NODEF.EQ.1)GO TO 25
        IF(KA.EQ.KF)GO TO 24
     25 IOPP=0
        A=TABLEA(KF,3)
        B=TABLEA(KF,2)
        IL=KF
C
C       CHECK FOR A 0 OR 1 MIL BRACKET
C
      1 IL=IL-1
        IF(IL.EQ.0.AND.IOPP.EQ.0)GO TO 19
        IF(IL.EQ.0)GO TO 2
        C=TABLEA(IL,2)
        IF(B.EQ.C)GO TO 1
        IOPP=1
        D=TABLEA(IL,3)
        DIFF=D-A
        IF(ABS(DIFF).LE.ONE)GO TO 21
        GO TO 1
C
C        CHECK FOR A TWO MIL BRACKET
C
      2 IL=KF
      3 IL=IL-1
        IF(IL.EQ.0)GO TO 4
        C=TABLEA(IL,2)
        IF(B.EQ.C)GO TO 3
        D=TABLEA(IL,3)
        DIFF=D-A
        IF(ABS(DIFF).LE.TWO)GO TO 22
        GO TO 3
C
C       CHECK FOR A FIVE MIL OR LESS BRACKET
C
      4 IL=KF
      5 IL=IL-1
        IF(IL.EQ.0)GO TO 6
        C=TABLEA(IL,2)
        IF(B.EQ.C)GO TO 5
        D=TABLEA(IL,3)
        DIFF=D-A
        IF(ABS(DIFF).GT.FIVE)GO TO 5
        ADD=TWO
        GO TO 19
C
```

```
C      THE BRACKET IS GREATER THAN FIVE MILS
C
    6 IF(ADD.EQ.TWO)GO TO 19
      IL=KF
      II=0
      DO 7 IJ=1,50
      STORE(IJ)=0.0
    7 CONTINUE
    8 IL=IL-1
      IF(IL.EQ.0.AND.II.GT.0)GO TO 9
      IF(IL.EQ.0)GO TO 19
      C=TABLEA(IL,2)
      IF(B.EQ.C)GO TO 8
      D=TABLEA(IL,3)
      DIFF=D-A
      II=II+1
      STORE(II)=ABS(DIFF)
      GO TO 8
C
C      SELECT THE MINIMUM BRACKET FOR COMPARISON WITH LAST
C      DEFLECTION FIRED
C
    9 Z1=STORE(1)
      TWOADD=ADD*2.0
      IF(II.EQ.1.AND.NODEF.EQ.1)GO TO 17
      IF(II.EQ.1)GO TO 11
      DO 10 IK=2,II
      Z2=STORE(IK)
      IF(Z2.LT.Z1)Z1=Z2
   10 CONTINUE
   11 IF(Z1.GT.TWOADD)ICPF=0
      IF(Z1.GE.TWOADD)GO TO 19
      IF(NODEF.EQ.1)GO TO 17
      IF(Z1.EQ.ADD)GO TO 14
      IF(Z1.LT.ADD.AND.ADD.EQ.FOUR)GO TO 16
      IF(Z1.LT.ADD.AND.ADD.EQ.EIGHT)GO TO 12
      IF(Z1.LT.ADD.AND.ADD.EQ.SIXTEN)GO TO 13
      Z3=Z1-ADD
      SPLIT=ADD*0.5
      IF(Z3.GE.SPLIT)GO TO 17
      GO TO 16
   12 ADD=ADD*0.5
      IF(Z1.LT.ADD)GO TO 16
      GO TO 17
   13 ADD=ADD*0.5
      IF(Z1.LT.ADD)GO TO 12
      GO TO 17
   14 ADD=ADD*0.5
      IF(B.GT.0)GO TO 15
      DEFLEC=DEFLEC+ADD
      GO TO 24
   15 DEFLEC=DEFLEC-ADD
      GO TO 24
   16 ADD=ADD*0.5
   17 CORR=Z1*0.5
      DUMMY=0.0
      BD=0.0
      CORR=FDCDCR(RN,DUMMY,CORR,BD)
      IF(B.GT.0)GO TO 18
      DEFLEC=DEFLEC+CORR
      GO TO 24
   18 DEFLEC=DEFLEC-CORR
      GO TO 24
   19 IF(B.GT.0)GO TO 20
      DEFLEC=DEFLEC+ADD
      GO TO 24
   20 DEFLEC=DEFLEC-ADD
      GO TO 24
   21 IGOOD=1
      GO TO 24
   22 IF(B.GT.0)GO TO 23
      DEFLEC=DEFLEC+ONE
```

```
      IGOOD=1
      GO TO 24
   23 DEFLEC=DEFLEC-ONE
      IGOOD=1
   24 RETURN
      END


      FUNCTION FORKF(X,Y,I)
C
C     THIS FUNCTION DETERMINES THE FIRE FOR EFFECT FORK TO
C     THE NEAREST EVEN MIL
C
C     X- GUN TARGET RANGE
C
C     Y- SUM OF ALL RANGE CORRECTIONS
C
C     I- THE POWDER CHARGE
C
      RANGE=X+Y
      IF(I.EQ.61)GO TO 8
      IF(I.EQ.59)GO TO 7
      IF(I.EQ.51)GO TO 6
      IF(I.EQ.7)GO TO 4
      IF(I.EQ.6)GO TO 3
      IF(I.EQ.5)GO TO 2
      IF(I.EQ.4)GO TO 1
      IF(RANGE.LT.3550.0)GO TO 10
      IF(RANGE.LT.4250.0)GO TO 11
      FORK=80.0
      GO TO 5
   10 FORK=40.0
      GO TO 5
   11 FORK=60.0
      GO TO 5
    1 IF(RANGE.LT.5150.0)GO TO 20
      FORK=60.0
      GO TO 5
   20 FORK=40.0
      GO TO 5
    2 FORK=40.0
      GO TO 5
    3 IF(RANGE.LT.7950.0)GO TO 30
      FORK=80.0
      GO TO 5
   30 FORK=60.0
      GO TO 5
    4 FORK=60.0
      GO TO 5
    6 IF(RANGE.LT.5250.0)GO TO 60
      FORK=60.0
      GO TO 5
   60 FORK=40.0
      GO TO 5
    7 FORK=20.0
      GO TO 5
    8 IF(RANGE.LT.9750.0)GO TO 81
      IF(RANGE.LT.10250.0)GO TO 82
      FORK=140.0
      GO TO 5
   81 FORK=100.0
      GO TO 5
   82 FORK=120.0
    5 FORKF=FORK
      RETURN
      END
```

```
      FUNCTION FORKT(X,Y,I)
C
C     THIS FUNCTION DETERMINES THE COMPUTATIONAL FORK VALUE
C     TO NEAREST MIL
C
C     X- GUNTARGET RANGE
C     Y- SUM OF ALL RANGE CORRECTIONS
C
C     I- THE POWDER CHARGE
C
      RANGE=X+Y
      IF(I.EQ.61)GO TO 8
      IF(I.EQ.59)GO TO 7
      IF(I.EQ.51)GO TO 6
      IF(I.EQ.7)GO TO 4
      IF(I.EQ.6)GO TO 3
      IF(I.EQ.5)GO TO 2
      IF(I.EQ.4)GO TO 1
      IF(RANGE.LT.3550.0)GO TO 10
      IF(RANGE.LT.3950.0)GO TO 11
      IF(RANGE.LT.4250.0)GO TO 12
      FORK=70.0
      GO TO 5
   10 FORK=40.0
      GO TO 5
   11 FORK=50.0
      GO TO 5
   12 FORK=60.0
      GO TO 5
    1 IF(RANGE.LT.4550.0)GO TO 20
      IF(RANGE.LT.5150.0)GO TO 21
      FORK=50.0
      GO TO 5
   20 FORK=30.0
      GO TO 5
   21 FORK=40.0
      GO TO 5
    2 IF(RANGE.LT.6150.0)GO TO 30
      FORK=40.0
      GO TO 5
   30 FORK=30.0
      GO TO 5
    3 IF(RANGE.LT.7950.0)GO TO 40
      FORK=70.0
      GO TO 5
   40 FORK=60.0
      GO TO 5
    4 IF(RANGE.LT.9550.0)GO TO 50
      FORK=60.0
      GO TO 5
   50 FORK=50.0
      GO TO 5
    6 IF(RANGE.LT.5250.0)GO TO 60
      FORK=50.0
      GO TO 5
   60 FORK=40.0
      GO TO 5
    7 FORK=10.0
      GO TO 5
    8 IF(RANGE.LT.9750.0)GO TO 81
      IF(RANGE.LT.10050.0)GO TO 82
      IF(RANGE.LT.10250.0)GO TO 83
      FORK=130.0
      GO TO 5
   81 FORK=100.0
      GO TO 5
   82 FORK=110.0
      GO TO 5
```

```
   83 FCRK=120.0
    5 FCRKT=FCRK
      RETURN
      END
C


      FUNCTION RAN(J)
C
C     THIS FUNCTION GENERATES  UNIFORM(0,1) AND NORMAL(0,1)
C     RANDOM NUMBERS
C
C     FOR J LT 0 SET INITIAL VALUE OF GENERATOR
C     FOR J EQUAL 0 GENERATE NORMAL (0,1) NUMBER
C     FOR J GT 0 GENERATE UNIFORM (0,1) NUMBER
C
      IF(J.GE.0)GO TO 10
      IX=1-2*J
      X=0
      GO TO 150
   10 IX=IX*65539
      IF(IX.LT.0)IX=IX+2147483647+1
      X=FLOAT(IX)*.4656613E-9
      IF(J.NE.0)GO TO 150
      DO 100 I=1,11
      IX=IX*65539
      IF(IX.LT.0)IX=IX+2147483647+1
  100 X=X+FLOAT(IX)*.4656613E-9
      X=X-6.0
  150 RAN=X
      RETURN
      END


      FUNCTION ROTGND(X,Y,Z,W)
C
C     THIS FUNCTION TRANSFORMS BURST DEVIATION FROM THE OB-
C     SERVER-TARGET TO THE GUN TARGET COORDINATE SYSTEM
C
C     X- OBSERVER COORDINATE OF BURST DEVIATION MISS DIS-
C        TANCE
C     Y- OBSERVER COORDINATE OF BURST RANGE MISS DISTANCE
C     Z- SIN OF ANGLE T
C     W- COS OF ANGLE T
C
      ROTGND=X*W-Y*Z
      RETURN
      END
C
C


      FUNCTION ROTGNR(X,Y,Z,W)
C
C     THIS FUNCTION TRANSFORMS BURST RANGE FROM THE OBSERVER
C     TARGET TO THE GUN TARGET COORDINATE SYSTEM
C
C     X- OBSERVER COORDINATE OF BURST DEVIATION MISS DIS-
C        TANCE
C     Y- OBSERVER COORDINATE OF BURST RANGE MISS DISTANCE
C     Z- SIN OF ANGLE T
C     W- COS OF ANGLE T
C
      ROTGNR=X*Z+Y*W
      RETURN
      END
C
C
C
```

```
      FUNCTION ROTFOD(X,Y,Z,W)
C
C     THIS FUNCTION TRANSFORMS BURST DEVIATION FROM THE GUN
C     TARGET TO THE OBSERVER TARGET COORDINATE SYSTEM
C
C     X- GUN COORDINATE OF BURST DEVIATION MISS DISTANCE
C     Y- GUN COORDINATE OF BURST RANGE MISS DISTANCE
C     Z- SIN OF ANGLE T
C     W- COS OF ANGLE T
C
      ROTFOD=X*W+Y*Z
      RETURN
      END
C
C
C


      FUNCTION ROTFOR(X,Y,Z,W)
C
C     THIS FUNCTION TRANSFORMS BURST RANGE FROM THE GUN-
C     TARGET TO THE OBSERVER TARGET COORDINATE SYSTEM
C
C     X- GUN COORDINATE OF BURST DEVIATION MISS DISTANCE
C     Y- GUN COORDINATE OF BURST RANGE MISS DISTANCE
C     Z- SIN OF ANGLE T
C     W- COS OF ANGLE T
C
      ROTFOR=Y*W-X*Z
      RETURN
      END


      FUNCTION FDCRCR(X,C,G,R)
C
C     THIS FUNCTION COMPUTES RANGE CORRECTION IN METERS
C     SUBJECT TO 1 MIL OR 0.1 MIL QUADRANT ELEVATION SETTING
C     LIMITATION
C
C     X- RANGE SHIFT REQUESTED
C     C- THE C-FACTOR
C     G- GUN CREW ERROR STANDARD DEVIATION IN APPLYING RE-
C        QUESTED ELEVATION SETTING
C     R- INDEX TO DETERMINE IF CORRECTIONS CORRESPOND TO 1
C        OR 0.1 MILS
C
      Z=C*X/100.0
      IF(R.GT.0.0)ZZ=RDOFF(Z)
      IF(R.GT.0.0)GO TO 3
      N=IFIX(Z)
      IF(Z.LT.0.0)GO TO 1
      IF(ABS(Z-N).GE..5)N=N+1
      GO TO 2
    1 IF(ABS(Z-N).GE..5)N=N-1
    2 ZZ=FLOAT(N)
    3 E=ZZ+RAN(0)*G
      FDCRCR=E*100.0/C
      RETURN
      END
C
C
```

```
      FUNCTION FDCDCR(X,Y,W,G)
C
C     THIS FUNCTION COMPUTES DEFLECTION SHIFT IN METERS SUB-
C     JECT TO 1 MIL DEFLECTION SETTING LIMITATION
C
C     X- REPORTED GUN TARGET RANGE
C     Y- RANGE MISS DISTANCE OF BURST
C     W- THE DEVIATION CORRECTION IN METERS
C     G- GUN CREW ERROR STANDARD DEVIATION  IN APPLYING
C        DEFLECTION SETTING
C
      TOTRG=X+Y
      Z=W*1000.0/TOTRG
      N=IFIX(Z)
      IF(Z.LT.0.0)GO TO 1
      IF(ABS(Z-N).GE..5)N=N+1
      GO TO 2
    1 IF(ABS(Z-N).GE..5)N=N-1
    2 E=FLOAT(N)+RAN(0)*G
      FDCDCR=E*TOTRG/1000.0
      RETURN
      END
C
C


      FUNCTION RDOFF(Y)
C
C     THIS ROUTINE ROUNDS OFF INPUT TO NEAREST 10 METERS
C
C     Y- THE  INPUT VALUE TO BE ROUNDED
C
      N=IFIX(Y)/10
      IF(Y.LT.0.0) GO TO 5
      IF(IABS(IFIX(Y)-10*N).GE.5.0) N=N+1
      GO TO 7
    5 IF(IABS(IFIX(Y)-10*N).GE.5.0) N=N-1
    7 RDOFF=10*FLOAT(N)
      RETURN
      END

      FUNCTION CFCTR(X,Y,I)
C
C     THIS FUNCTION COMPUTES THE APPROPRIATE C-FACTOR
C
C     X- GUN TARGET RANGE
C     Y- TOTAL RANGE SHIFTS
C     Z- THE CHARGE FIRED
C
      RANGE=X+Y
      IF(I.EQ.61)GO TO 8
      IF(I.EQ.59)GO TO 7
      IF(I.EQ.51)GO TO 6
      IF(I.EQ.7)GO TO 4
      IF(I.EQ.6)GO TO 3
      IF(I.EQ.5)GO TO 2
      IF(I.EQ.4)GO TO 1
      C=RANGE*0.02+22.0
      GO TO 5
    1 C=RANGE*0.012+19.0
      GO TO 5
    2 C=RANGE*0.007+22.0
      GO TO 5
    3 C=RANGE*0.008-3.0
      GO TO 5
    4 C=RANGE*0.005+4.0
      GO TO 5
```

```
6  C=RANGE*0.006+28.0
   GO TO 5
7  C=RANGE*0.004+37.0
   GO TO 5
8  C=0.02*RANGE-115.0
5  CFCTR=C
   RETURN
   END
```

APPENDIX G X-BAR PRECISION FIRE SIMULATION PROGRAM LISTING

THE PURPOSE OF THIS APPENDIX IS TO PROVIDE THE COMPUTER PROGRAM LISTING OF THE X-BAR PRECISION FIRE SYSTEM'S SIMULATION AS PRESENTED IN SECTION V.THE ALPHABETICAL LISTING AND DESCRIPTION OF VARIABLE NAMES USED WITHIN THE PROGRAM ARE AS FOLLOWS:

A-	TARGET SEMI-MAJOR AXIS LENGTH
ADJCI-	REGISTRATION RANGE ERROR
ADP-	CONTROL VARIABLE FOR ROUND OFF RULES IN COMPUTING MISS DISTANCES -2.0 NO ROUNDING OFF 2.0 ROUNDING TO NEAREST WHOLE INTEGER
ARMIS-	SUM OF ABSOLUTE REGISTRATION DEVIATION ERRORS
ANGRO-	THE TRUE ANGLE T
ANGLT-	THE OBSERVER REPORTED ANGLE T IN MILS
AVDFER-	AVERAGE REGISTRATION DEVIATION ERROR
AVJRDS-	AVERAGE NUMBER OF ROUNDS FIRED FOR A REGISTRATION
AVMISS-	AVERAGE RANGE ERROR OF A REGISTRATION
AVRGER-	AVERAGE RANGE ERROR
B-	TARGET SEMI-MINOR AXIS LENGTH IN METERS
BD-	GUN CREW ERROR STANDARD DEVIATION IN SETTING DEFLECTION IN 1 MIL INCREMENTS
BR-	GUN CREW ERROR STANDARD DEVIATION IN SETTING ELEVATION IN 0.1 MIL INCREMENTS
C-	THE COMPUTED C-FACTOR
CHECK-	DEVIATION ERROR OF REGISTRATION IN METERS
CORR-	FIRE DIRECTION CENTER COMPUTED RANGE CORRECTION
CT-	COSINE OF ANGLE T
CT1-	COSINE OF TARGET ORIENTATION ANGLE
CTRO-	COSINE OF TRUE ANGLE T
DEFAPL-	TOTAL DEFLECTION CORRECTIONS APPLIED IN METERS
DEFLEC-	DEFLECTION DIFFERENCE BETWEEN AIM POINT AND TRUE TARGET CENTER IN METERS

DEFTRY-	DEFLECTION CORRECTION TRIAL COUNTER
DF-	GUN TARGET BURST DEFLECTION MISS DISTANCE IN METERS
DFMISS-	SUM OF REGISTRATION DEVIATION ERRORS
DFSQ-	SUM OF SQUARES OF REGISTRATION DEVIATION ERRORS
DM-	MEAN ABSOLUTE REGISTRATION DEVIATION ERROR
DTSQ-	SQUARE OF RADIAL MISS DISTANCE
ERROTV-	LASED BASE RANGE ERROR
FDCDF-	FIRE DIRECTION CENTER DEFLECTION MISS DISTANCE
FDCRG-	FIRE DIRECTION CENTER RANGE MISS DISTANCE
FCANER-	THE STANDARD DEVIATION OF ANGLE T ERROR IN MILS
FCDF-	BURST DEVIATION MISS DISTANCE IN METERS IN THE OBSERVER TARGET COORDINATE SYSTEM
FCDFS-	OBSERVER ESTIMATE OF DEVIATION MISS DISTANCE
FCRG-	BURST RANGE MISS DISTANCE IN METERS IN THE OBSERVER TARGET COORDINATE SYSTEM
FCRGS-	OBSERVER ESTIMATE OF RANGE MISS DISTANCE
ICHG-	POWDER CHARGE PARAMETER
IDC-	CONTROL VARIABLE FOR SPECIFYING ANGLE T
JRDS-	NUMBER OF ROUNDS FIRED IN A MISSION
JSQ-	SQUARE OF NUMBER OF ROUNDS FIRED IN A MISSION
KTGT-	TARGET HIT CONTROL VARIABLE
LTGTS-	CUMULATIVE TOTAL NUMBER OF TARGETS STRUCK
MISDIS-	RADIAL ERROR OF A REGISTRATION IN METERS
MISTOT-	SUM TOTAL OF ALL RADIAL ERRORS
MTGT-	DESIGNATOR FOR TYPE OF MISSION TO EVALUATE 0 IMPLIES REGISTRATION 1 IMPLIES DESTRUCTION
N-	ROUNDS FIRED COUNTER
NI-	MISSIONS FIRED COUNTER
NITER-	POSITEVELY SPOTTED ROUND
NCTRGT-	NUMBER OF TARGETS STRUCK
NRFRD-	NUMBER OF ROUNDS FIRED

NROUND-	TOTAL NUMBER OF ROUNDS TO FIRE FOR EACH REGISTRATION
NTGT-	TARGET HIT COUNTER
OTERR-	THE BASE RANGE ERROR
OTRG-	THE OBSERVER TARGET RANGE IN METERS
PED-	PROBABLE ERROR IN DEFLECTION
PER-	PROBABLE ERROR IN RANGE
R-	SPECIFIES HOW ELEVATION IS TO BE APPLIED -1.0 IMPLIES TO NEAREST .1 MILS 1.0 IMPLIES TO NEAREST 1 MIL
RANGE-	RANGE DIFFERENCE BETWEEN AIMPOINT AND TRUE TARGET CENTER IN METERS
RG-	GUN TARGET RANGE MISS DISTANCE OF BURST
RG1-	BURST RANGE MISS DISTANCE IN TARGET COORDINATE SYSTEM
RGMISS-	SUM OF REGISTRATION RANGE ERRORS
RGSHFT-	TOTAL OF APPLIED RANGE CORRECTIONS
RGSQ-	SUM OF THE SQUARES OF REGISTRATION RANGE ERRORS
RM-	MEAN ABSOLUTE RANGE ERROR OF A REGISTRATION
RN-	TABULAR FIRING TABLE GUN TARGET RANGE
SDDF-	STANDARD DEVIATION OF AVERAGE REGISTRATION DEVIATION ERRORS
SDJR-	STANDARD DEVIATION OF ROUNDS FIRED FOR A REGISTRATION
SDMD-	STANDARD DEVIATION OF DEVIATION ERRORS OF A REGISTRATION
SDRG-	STANDARD DEVIATION OF AVERAGE RANGE ERRORS OF A REGISTRATION
START-	RANDOM NUMBER GENERATOR INITIALIZER
ST-	SIN OF ANGLE T
ST1-	SIN OF TARGET ORIENTING ANGLE
STFO-	SIN OF TRUE ANGLE T
SYSERD-	OBSERVER BURST AZIMUTH LASING ERROR IN MILS
TETAFO-	TRUE ANGLE T IN RADIANS

TGTANG- TARGET SEMI-MAJOR AXIS ANGULAR ORIENTATION IN MILS

THETA- ANGLE T IN RADIANS

THETA1- TARGET ORIENTING ANGLE IN RADIANS

ZIL- A MISSION COUNTER

ZN- MULTIPLIER FRACTION FOR COMPUTATION OF RANGE AND DEFLECTION CORRECTIONS

```
C        PROGRAM LISTING OF X-BAR PRECISION FIRE SIMULATION
C
C        USER INFORMATION.
C        THE PROGRAM AS WRITTEN WILL INVESTIGATE ONLY THE
C        FOLLOWING AMMUNITION PARAMETER INPUTS EXTRACTED FROM
C        FIRING TABLES TFT 155-AH-2
C
C        CHARGE       RANGE(RN)    ICHG     PER     PED
C         5GB           2000        59       7       1
C         5WB           5500        51      20       3
C         5GB           6000         5      13       3
C          6           10000        61      34       5
C
C        FOR OTHER PARAMETER VALUES THE USER MUST MAKE APPRO-
C        PRIATE CHANGES TO FORKF, FORKT, AND CFCTR ROUTINES
C
C        THE USER MUST SPECIFY THE FOLLOWING INPUT PARAMETERS:
C
C        A-        THE TARGET SEMIMAJOR AXIS IN METERS
C        B-        THE TARGET SEMIMINOR AXIS IN METERS
C        TGTANG-   THE TARGET ORIENTING ANGLE IN MILS
C        MTGT-     SET MTGT=0 IF REGISTRATION DESIRED
C                  SET MTGT=1 IF DESTRUCTION DESIRED
C        ADP-      SET ADP=1 TO SIMULATE FIRE DIRECTION CENTER
C                  RANGE CORRECTIONS TO NEAREST 10 METERS
C        ANGLT-    SPECIFY THE ANGLE T TO BE INVESTIGATED IN MILS
C        FOANER-   SPECIFY THE STANDARD DEVIATION OF OBSERVER
C                  ANGLE T ERROR IN MILS
C        OTRG-     THE OBSERVER TARGET RANGE
C        ICHG-     THE POWDER TYPE AND CHARGE
C        RN-       THE RANGE IN METERS TO GO WITH ICHG
C        PER-      APPROPRIATE PROBABLE ERROR IN RANGE CORRES-
C                  PONDING TO ICHG
C        PED-      APPROPRIATE PROBABLE ERROR IN DEFLECTION CORR-
C                  ESPONDING TO ICHG
C        BR-       GUN CREW ERROR STANDARD DEVIATION IN APPLYING
C                  ELEVATION SETTINGS IN 0.1 MIL INCREMENTS.;OR
C                  EXAMPLE,A 1 MIL STANDARD DEVIATION WOULD BE
C                  BR=10.0
C        BD-       GUN CREW ERROR STANDARD DEVIATION IN APPLYING
C                  DEFLECTION SETTINGS IN MILS.FOR EXAMPLE,A 1.5
C                  MIL STANDARD DEVIATION WOULD BE BD=1.5
C        SYSERR-   THE OBSERVER RANGE LASING ERROR IN METERS
C        SYSERD-   THE OBSERVER DEFLECTION LASING ERROR IN MILS
C        ERROTV-   THE BASE RANGE ERROR IN METERS
C
         REAL MRE1,MRSQ,MRE,MISDIS,OTRG,MISTOT
         DIMENSION ADJCI(10),CHECK(10),NOTRGT(10),NRDS(10),NRFR
        1D(10),MISDIS(10),DTSQ(10),MISTOT(10),RGMISS(10),ARMIS(
        110),RGSQ(10),DFMISS(10),AFMIS(10),DFSQ(10),IRDS(10),RD
        1SQ(10),JRDS(10),JSQ(10),LTGTS(10),AVMISS(10),SDMD(10),
        1AVRGER(10),SDRG(10),AVDFER(10),SDDF(10),AVRDS(10),SDRD
        1(10),SDJR(10),RM(10),DM(10),AVJRDS(10)
         IDC=-2
C
C        THE AMMUNITION PARAMETERS ARE SET
C
         ICHG=59
         RN=2000.0
         PER=7.0
         PED=1.0
C
C        THE ERROR PARAMETERS ARE SET
C
         SYSERR=0.0
         SYSERD=0.0
         ERROTV=0.0
         BR=0.0
         BD=0.0
         FOANER=0.0
         ADP=2.0
         R=-1.0
```

```
C
C     MISSION TYPE TO BE INVESTIGATED IS SPECIFIED
C
      MTGT=0
      NROUND=10
C
C     TARGET PARAMETERS ARE SPECIFIED
C
      A=5.0
      B=5.0
      TGTANG=1600.0
C
C     ANGLE T IS SPECIFIED
C
      ANGLT=10.0
      GO TO 502
  500 CONTINUE
      ANGLT=800.0
      GO TO 502
  501 CONTINUE
      ANGLT=1600.0
  502 TWOPI=6.283184
C
C     VECTOR ARRAYS ARE ZEROED OUT
C
      DO 854 I=1,10
      AVRGER(I)=0.0
      DTSQ(I)=0.0
      MISTOT(I)=0.0
      RGMISS(I)=0.0
      ARMIS(I)=0.0
      RGSQ(I)=0.0
      DFMISS(I)=0.0
      AFMIS(I)=0.0
      DFSQ(I)=0.0
      IRDS(I)=0
      RDSQ(I)=0.0
      JRDS(I)=0
      JSQ(I)=0
      LTGTS(I)=0
      AVMISS(I)=0.0
      SDMD(I)=0.0
      SDRG(I)=0.0
      AVDFER(I)=0.0
      SDDF(I)=0.0
      AVRDS(I)=0.0
      SDRD(I)=0.0
      AVJRDS(I)=0.0
      SDJR(I)=0.0
      RM(I)=0.0
      DM(I)=0.0
  854 CONTINUE
      IDD=IDD+1
C
C     OBSERVER TARGET RANGE IS ESTABLISHED
C
      OTRG=2500
C
C     THETA IS CONVERSION OF ANGLE T FROM MILS TO RADIANS.
C
      THETA=(ANGLT/6400.0)*TWOPI
      ST=SIN(THETA)
      CT=COS(THETA)
C
C     THETA1 IS CONVERSION OF TARGET ORIENTING ANGLE FROM
C     MILS TO RADIANS
C
      THETA1=(TGTANG/6400.0)*TWOPI
      ST1=SIN(THETA1)
      CT1=COS(THETA1)
C
C     THE RANDOM NUMBER GENERATOR IS INITIALIZED.
```

```
C
      START=RAN(-351)
      NI=0
  200 NI=NI+1
C
C     COUNTERS AND VECTOR ARRAYS FOR EACH MISSION FIRED ARE
C     ZEROED OUT
C
      ZIL=0.0
      NITER=0
      KTGT=0
      RGSHFT=0.0
      DEFAPL=0.0
      NTGT=0
      N=0
      DEFTRY=0.0
      DO 853 I=1,10
      ADJCI(I)=0.0
      CHECK(I)=0.0
      NOTRGT(I)=0
      NRDS(I)=0
      NRFRD(I)=0
      MISDIS(I)=0.0
  853 CONTINUE
C
C     THE ANGLE T ERROR IS COMPUTED
C
      ANGFO=ANGLT+(RAN(0))*FOANER
      TETAFO=(ANGFO/6400.0)*TWOPI
      STFO=SIN(TETAFO)
      CTFO=COS(TETAFO)
C
C     BASE RANGE ERROR IS COMPUTED
C
      CTERR=(RAN(1))*ERROTV
      IF(RAN(1).LT..5)CTERR=-CTERR
C
C     THE INITIAL BURST LOCATION OF EACH MISSION IS SET
C
      RANGE=RAN(1)*400.0
      IF(RAN(1).LT..5)RANGE=-RANGE
      DEFLEC=RAN(1)*200.0
      IF(RAN(1).LT..5)DEFLEC=-DEFLEC
    1 N=N+1
C
C     THE C FACTOR IS COMPUTED
C
      C=CFCTR(RN,RGSHFT,ICHG)
C
C     THE BURST LOCATION IN THE GUN TARGET COORDINATE SYSTEM
C     IS ESTABLISHED
C
      RG=(RAN(0))*PER/.6745+RANGE
      DF=(RAN(0))*PED/.6745+DEFLEC
C
C     BURST LOCATION IN TARGET COORDINATE SYSTEM IS ESTAB-
C     LISHED AND A DETERMINATION OF A TARGET HIT IS MADE
C
      RG1=ROTFOR(DF,RG,ST1,CT1)
      DF1=ROTFOD(DF,RG,ST1,CT1)
      IF(ABS(RG1).LT.A.AND.ABS(DF1).LT.B)GO TO 2
C
C     BURST LOCATION IS TRANSFORMED FROM THE GUN-TARGET
C     TO OBSERVER TARGET COORDINATE SYSTEM
C
      FORG=ROTFOR(DF,RG,STFO,CTFO)
      FODF=ROTFOD(DF,RG,STFO,CTFO)
C
C     FORWARD OBSERVER ESTIMATES RANGE AND DEVIATION MISS
C     DISTANCES
C
      FODFS=ERRDF(OTRG,FODF,FORG,SYSERD,CTERR)
```

```
      FORGS=RNDONE(ERRFCN(OTRG,FORG,SYSERR,CTERR),ACP)
C
C     FORWARD OBSERVER ESTIMATE OF MISS DISTANCE IS TRANS-
C     FORMED FROM THE OBSERVER TARGET TO THE GUN TARGET
C     (FIRE DIRECTION CENTER) COORDINATE SYSTEM
C
      FDCRG=RCTGNR(FODFS,FORGS,ST,CT)
      FDCDF=RCTGND(FODFS,FORGS,ST,CT)
      GO TO 3
    2 NTGT=NTGT+1
      IF(NTGT.EQ.1)NITER=NROUND-1
      KTGT=1
    3 NITER=NITER+1
C
C     RANGE AND DEFLECTION CORRECTIONS TO FIRE THE NEXT
C     ROUND ARE COMPUTED
C
      ZIL=ZIL+1.0
      IF(KTGT.EQ.1)GO TO 4
      ZN=1.0/ZIL
      CORR=-ZN*FDCRG
      CORR=FDCRCR(CORR,C,BR,R)
      GO TO 5
    4 CORR=0.0
    5 RGSHFT=RGSHFT+CORR
      RANGE=RANGE+CORR
      DEFTRY=DEFTRY+1.0
      IF(KTGT.EQ.1)GO TO 6
      APPLDF=-(FDCDF/DEFTRY)
      APPLDF=FDCDCR(RN,RANGE,APPLDF,BD)
      GO TO 7
    6 APPLDF=0.0
    7 DEFLEC=DEFLEC+APPLDF
      KTGT=0
C
C     REGISTRATION RANGE AND DEVIATION ERRORS ARE COMPUTED
C     AFTER EACH ROUND FIRED
C
      ADJCI(NITER)=RANGE
      CHECK(NITER)=DEFLEC
      NCTRGT(NITER)=NTGT
      NRFRD(NITER)=N
      MISDIS(NITER)=SQRT(ADJCI(NITER)*ADJCI(NITER)+CHECK(NIT
     1ER)*CHECK(NITER))
      IF(NROUND.EQ.NITER)GO TO 8
      GO TO 1
    8 CONTINUE
C
C     TALLIES ARE MADE FOR SUBSEQUENT STATISTICAL ANALYSIS
C
      DO 800 I=1,NITER
      DTSQ(I)=DTSQ(I)+MISDIS(I)*MISDIS(I)
      MISTOT(I)=MISTOT(I)+MISDIS(I)
      RGMISS(I)=RGMISS(I)+ADJCI(I)
      ARMIS(I)=ARMIS(I)+ABS(ADJCI(I))
      RGSQ(I)=RGSQ(I)+ADJCI(I)*ADJCI(I)
      DFMISS(I)=DFMISS(I)+CHECK(I)
      AFMIS(I)=AFMIS(I)+ABS(CHECK(I))
      DFSQ(I)=DFSQ(I)+CHECK(I)*CHECK(I)
      JRDS(I)=JRDS(I)+NRFRD(I)
      JSQ(I)=JSQ(I)+NRFRD(I)*NRFRD(I)
      LTGTS(I)=LTGTS(I)+NCTRGT(I)
  800 CONTINUE
      IF(NI-25)200,300,300
  300 ZIP=FLOAT(NI)
      WRITE(6,9011)RN,PER,PED
      WRITE(6,9004)ANGLT,HALFS
      WRITE(6,100)SYSERR,SYSERD
      WRITE(6,1100)FOANER
      DO 801 I=1,NITER
      AVMISS(I)=MISTOT(I)/ZIP
      SDMD(I)=SQRT((DTSQ(I)/ZIP)-AVMISS(I)*AVMISS(I))
```

```
      WRITE(6,9907)I
      WRITE(6,9000)AVMISS(I),SDMD(I)
      AVRGER(I)=RGMISS(I)/ZIP
      SDRG(I)=SQRT((RGSQ(I)/ZIP)-AVRGER(I)*AVRGER(I))
      WRITE(6,9001)AVRGER(I),SDRG(I)
      AVDFER(I)=DFMISS(I)/ZIP
      SDDF(I)=SQRT((DFSQ(I)/ZIP)-AVDFER(I)*AVDFER(I))
      WRITE(6,9002)AVDFER(I),SDDF(I)
      RM(I)=ARMIS(I)/ZIP
      DM(I)=AFMIS(I)/ZIP
      WRITE(6,9906)RM(I),DM(I)
      AVJRDS(I)=JRDS(I)/ZIP
      SDJR(I)=SQRT((JSQ(I)/ZIP)-AVJRDS(I)*AVJRDS(I))
      WRITE(6,9005)AVJRDS(I),SDJR(I)
      WRITE(6,9900)LTGTS(I)
  801 CONTINUE
      IF(IDO)500,501,503
 1000 FORMAT(' ',T7,'P RANGE ERROR=',F9.2,T60,'P DEVIATION E
     1RROR=',F9.2)
 1100 FORMAT(' ',T7,'STANDARD DEVIATION OF ANGLE T ERROR=',F
     19.2)
 9011 FORMAT('1',T7,'RANGE=',F9.2,7X,'PER=',F6.2,7X,'PED=',F
     16.2)
 7000 FORMAT(' ',T7,'ROUND NUMBER=',I4,10X,'AIM POINT RANGE=
     1',F9.3,10X,'AIM POINT DEVIATION=',F9.3)
 9004 FORMAT('0',T7,'ANGLE T=',F9.2,T60,'HALFS=',F6.2)
 9000 FORMAT('0',T7,'AVERAGE MISS DISTANCE=',F9.2,T60,'STD D
     1EV=',F9.2)
 9001 FORMAT(' ',T7,'AVERAGE RANGE ERROR=',F9.2,T60,'STD DEV
     1=',F9.2)
 9002 FORMAT(' ',T7,'AVERAGE DEFLECTION ERROR=',F9.2,T60,'ST
     1D DEV=',F9.2)
 9005 FORMAT(' ',T7,'AV FFE ROUNDS=',F6.2,T60,'STD DEV=',F6.
     12)
 9900 FORMAT(' ',T7,'TOTAL TARGETS STRUCK=',I6)
 9100 FORMAT('0',T7,'STD DEV GUN QE ERROR=',F6.2,T60,'STD DE
     1V OF GUN ERROR=',F6.2)
 9906 FORMAT(' ',T7,'ABSRANGE MISS=',F9.2,T60,'ABSDEVIATION
     1MISS=',F9.2)
 9907 FORMAT('0',T45,'FIRE FOR EFFECT ROUND NO:',I4)
  100 FORMAT(' ',T7,'FO RANGE ERROR=',F9.2,T60,'FO DEVIATION
     1ERROR=',F9.2)
  503 STOP
      END
```

X-BAR SIMULATION FUNCTIONAL PROGRAM LISTINGS

```
      FUNCTION RAN(J)
C
C     THIS FUNCTION GENERATES  UNIFORM(0,1) AND NORMAL(0,1)
C     RANDOM NUMBERS
C
C     FOR J LT 0 SET INITIAL VALUE OF GENERATOR
C     FOR J EQUAL 0 GENERATE NORMAL (0,I) NUMBER
C     FOR J GT 0 GENERATE UNIFORM (0,1) NUMBER
C
      IF(J.GE.0)GO TO 10
      IX=1-2*J
      X=0
      GO TO 150
   10 IX=IX*65539
      IF(IX.LT.0)IX=IX+2147483647+1
      X=FLOAT(IX)*.4656613E-9
      IF(J.NE.0)GO TO 150
      DO 100 I=1,11
      IX=IX*65539
      IF(IX.LT.0)IX=IX+2147483647+1
  100 X=X+FLOAT(IX)*.4656613E-9
      X=X-6.0
  150 RAN=X
      RETURN
      END


      FUNCTION ERRFCN(X,Y,W,Z)
C
C     THIS FUNCTION DETERMINES THE FORWARD OBSERVER ERROR
C     IN ESTIMATING ACTUAL RANGE OF THE BURST.
C
C     X-OBSERVER TARGET RANGE
C     Y-ACTUAL BURST LOCATION RELATIVE TO TARGET
C     W-OBSERVER SYSTEM ERROR IN RANGE
C     Z-BASE RANGE ERROR
C
      ZX=RAN(1)*W
      ERROR=ZX
      IF (RAN(1).GT..5)GO TO 1
      ERROR=-ERROR
    1 ERRG=Y+ERROR
      ERRFCN=ERRG+Z
      GO TO 3
    3 RETURN
      END


      FUNCTION ERRDF(X,Y,Z,W,U)
C
C     THIS FUNCTION DETERMINES FORWARD OBSERVER ERROR IN
C     SENSING DEFLECTION OF BURST
C
C     X-OBSERVER TARGET DISTANCE
C     Y-ACTUAL BURST DEFLECTION LOCATION RELATIVE TO TARGET
C     Z-ACTUAL BURST RANGE LOCATION IN RELATION TO TARGET
C     W-OBSERVER SYSTEM ERROR IN DEFLECTION
C     U-BASE RANGE ERROR
C
      BD=0.0
      TOTRG=X+Z+U
      ERROR=(W*0.001)*(RAN(1))*TOTRG
      IF(RAN(1).GT..5)GO TO 1
      ERROR=-ERROR
    1 ERDF=Y+ERROR
      ERRDF=FOCDOR(X,Z,ERDF,BD)
    3 RETURN
      END
```

```
      FUNCTION ROTGND(X,Y,Z,W)
C
C     THIS FUNCTION TRANSFORMS BURST DEVIATION FROM THE OB-
C     SERVER-TARGET TO THE GUN TARGET COORDINATE SYSTEM
C
C     X- OBSERVER COORDINATE OF BURST DEVIATION MISS DIS-
C        TANCE
C     Y- OBSERVER COORDINATE OF BURST RANGE MISS DISTANCE
C     Z- SIN OF ANGLE T
C     W- COS OF ANGLE T
C
      ROTGND=X*W-Y*Z
      RETURN
      END
C
C
      FUNCTION ROTGNR(X,Y,Z,W)
C
C     THIS FUNCTION TRANSFORMS BURST RANGE FROM THE OBSERVER
C     TARGET TO THE GUN TARGET COORDINATE SYSTEM
C
C     X- OBSERVER COORDINATE OF BURST DEVIATION MISS DIS-
C        TANCE
C     Y- OBSERVER COORDINATE OF BURST RANGE MISS DISTANCE
C     Z- SIN OF ANGLE T
C     W- COS OF ANGLE T
C
      ROTGNR=X*Z+Y*W
      RETURN
      END
C
C
C
      FUNCTION ROTFOD(X,Y,Z,W)
C
C     THIS FUNCTION TRANSFORMS BURST DEVIATION FROM THE GUN
C     TARGET TO THE OBSERVER TARGET COORDINATE SYSTEM
C
C     X- GUN COORDINATE OF BURST DEVIATION MISS DISTANCE
C     Y- GUN COORDINATE OF BURST RANGE MISS DISTANCE
C     Z- SIN OF ANGLE T
C     W- COS OF ANGLE T
C
      ROTFOD=X*W+Y*Z
      RETURN
      END
C
C
C
      FUNCTION ROTFOR(X,Y,Z,W)
C
C     THIS FUNCTION TRANSFORMS BURST RANGE FROM THE GUN-
C     TARGET TO THE OBSERVER TARGET COORDINATE SYSTEM
C
C     X- GUN COORDINATE OF BURST DEVIATION MISS DISTANCE
C     Y- GUN COORDINATE OF BURST RANGE MISS DISTANCE
C     Z- SIN OF ANGLE T
C     W- COS OF ANGLE T
C
      ROTFOR=Y*W-X*Z
      RETURN
      END
```

```
      FUNCTION FDCRCR(X,C,G,R)
C
C     THIS FUNCTION COMPUTES RANGE CORRECTION IN METERS
C     SUBJECT TO 1 MIL OR 0.1 MIL QUADRANT ELEVATION SETTING
C     LIMITATION
C
C     X- RANGE SHIFT REQUESTED
C     C- THE C-FACTOR
C     G- GUN CREW ERROR STANDARD DEVIATION IN APPLYING RE-
C        QUESTED ELEVATION SETTING
C     R- INDEX TO DETERMINE IF CORRECTIONS CORRESPOND TO 1
C        OR 0.1 MILS
C
      Z=C*X/100.0
      IF(R.GT.0.0)ZZ=RDOFF(Z)
      IF(R.GT.0.0)GO TO 3
      N=IFIX(Z)
      IF(Z.LT.0.0)GO TO 1
      IF(ABS(Z-N).GE..5)N=N+1
      GO TO 2
    1 IF(ABS(Z-N).GE..5)N=N-1
    2 ZZ=FLOAT(N)
    3 E=ZZ+RAN(0)*G
      FDCRCR=E*100.0/C
      RETURN
      END
C
C
      FUNCTION FDCDCR(X,Y,W,G)
C
C     THIS FUNCTION COMPUTES DEFLECTION SHIFT IN METERS SUB-
C     JECT TO 1 MIL DEFLECTION SETTING LIMITATION
C
C     X- REPORTED GUN TARGET RANGE
C     Y- RANGE MISS DISTANCE OF BURST
C     W- THE DEVIATION CORRECTION IN METERS
C     G- GUN CREW ERROR STANDARD DEVIATION  IN APPLYING
C        DEFLECTION SETTING
C
      TOTRG=X+Y
      Z=W*1000.0/TOTRG
      N=IFIX(Z)
      IF(Z.LT.0.0)GO TO 1
      IF(ABS(Z-N).GE..5)N=N+1
      GO TO 2
    1 IF(ABS(Z-N).GE..5)N=N-1
    2 E=FLOAT(N)+RAN(0)*G
      FDCDCR=E*TOTRG/1000.0
      RETURN
      END
C
C
      FUNCTION RDOFF(Y)
C
C     THIS ROUTINE ROUNDS OFF INPUT TO NEAREST 10 METERS
C
C     Y- THE  INPUT VALUE TO BE ROUNDED
C
      N=IFIX(Y)/10
      IF(Y.LT.0.0) GO TO 5
      IF(IABS(IFIX(Y)-10*N).GE.5.0) N=N+1
      GO TO 7
    5 IF(IABS(IFIX(Y)-10*N).GE.5.0) N=N-1
    7 RDOFF=10*FLOAT(N)
      RETURN
      END
```

```
      FUNCTION CFCTR(X,Y,I)
C
C     THIS FUNCTION COMPUTES THE APPROPRIATE C-FACTOR
C
C     X- GUN TARGET RANGE
C     Y- TOTAL RANGE SHIFTS
C     Z- THE CHARGE FIRED
C
      RANGE=X+Y
      IF(I.EQ.61)GO TO 8
      IF(I.EQ.59)GO TO 7
      IF(I.EQ.51)GO TO 6
      IF(I.EQ.7)GO TO 4
      IF(I.EQ.6)GO TO 3
      IF(I.EQ.5)GO TO 2
      IF(I.EQ.4)GO TO 1
      C=RANGE*0.02+22.0
      GO TO 5
    1 C=RANGE*0.012+19.0
      GO TO 5
    2 C=RANGE*0.007+22.0
      GO TO 5
    3 C=RANGE*0.008-3.0
      GO TO 5
    4 C=RANGE*0.005+4.0
      GO TO 5
    6 C=RANGE*0.006+28.0
      GO TO 5
    7 C=RANGE*0.004+37.0
      GO TO 5
    8 C=0.02*RANGE-115.0
    5 CFCTR=C
      RETURN
      END
C
C
      FUNCTION RNDONE(Z,W)
C
C     THIS FUNCTION ROUNDS OFF INPUT TO NEAREST UNIT VALUE
C
C     Z-INPUT TO BE ROUNDED TO NEAREST UNIT VALUE
C     W-IF VALUE GREATER THAN ONE ROUNDING IS DESIRED
C       IF VALUE IS LESS THAN ONE,ROUNDING NOT DESIRED
C
      IF(W.LT.1.0)GO TO 3
      N=IFIX(Z)
      IF(Z.LT.0.0)GO TO 1
      IF(ABS(Z-N).GE..5)N=N+1
      GO TO 2
    1 IF(ABS(Z-N).GE..5)N=N-1
    2 RND=FLOAT(N)
      GO TO 4
    3 RND=Z
    4 RNDONE=RND
      RETURN
      END
```

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. ABSTRACT

This thesis is addressed to the problem of determining optimal precision fire methods for the Field Artillery. The current precision fire technique has been in use by the Field Artillery since 1941. Because of the general acceptance that the method works, the procedure has remained relatively unchanged for 32 years; no documented evidence of previous efforts to establish an analytical basis for the procedure apparently exists. Employing the methods of stochastic approximation, the theoretical foundation for the current procedure is established. Using the developed theoretical foundation of the current precision fire method, a simplified, more efficient procedure is developed. In addition, an optimal precision fire procedure to be used when forward observers are equipped with laser range finders is presented. The procedures are compared analytically and through computer simulations to arrive at conclusions regarding simplicity, accuracy and economy of ammunition expenditures.

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